Star Tek—Exploiting the Final Frontier: Counterspace Operations in 2025

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Disclaimer

2025 is a study designed to comply with a directive from the chief of staff of the Air Force to examine the concepts, capabilities, and technologies the United States will require to remain the dominant air and space force in the future. Presented on 17 June 1996, this report was produced in the Department of Defense school environment of academic freedom and in the interest of advancing concepts related to national defense. The views expressed in this report are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States government.

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Executive Summary

Space superiority, like air superiority today, will be a vital core competency in the year 2025. US national security is already heavily leveraged in space—a trend which will increase in the future. Likewise, other countries and commercial interests will continue to seek the valuable "high ground" of space. Where space interests conflict, hostilities may soon follow. Protecting the use of space and controlling, when required, its advantage is the essence of counterspace.

This paper demonstrates the need for, and the means by which, counterspace operations will be conducted in the year 2025. A number of factors will drive the need for a robust counterspace capability in 2025. Space will be seen as a vital national interest based on its significant role in maintaining national security. In addition, the ability to operate freely in the space theater of operations will drive the United States (US) to implement capabilities to protect its vast array of space platforms as well as those of its friends and allies. Finally, the importance of space assets in achieving information dominance will force a serious examination of the requirement for developing offensive counterspace capabilities and placing nonnuclear weapons in space.

In order to field credible and effective counterspace capabilities, the US must take advantage of current leaps in computer technologies and nurture advances in other areas. Successes in miniaturization technologies, such as nanotechnology and microelectromechanical systems, will spawn advances in space detecting and targeting capabilities and space stealth technologies. In turn, kinetic and directed energy weapon systems will likely constitute the backbone of future offensive and defensive counterspace capabilities. A counterspace architecture must and will integrate enemy target detection, target identification, command and control, defensive counterspace capabilities, and offensive counterspace capabilities to expand the options available to future commanders.

The focus we place today on counterspace requirements will directly impact the space forces we field in year 2025. This paper identifies the need for counterspace and provides a variety of concepts to do the job. Each concept includes a system description, a concept of operations, and a discussion of possible

countermeasures. Finally, a systems analysis of counterspace concepts yields recommendations on key systems which should pay the greatest dividends in both the commercial and military arena. Offensive counterspace concepts recommended for future development are parasite microsatellites (robo-bugs), transatmospheric vehicles (TAVs), and a ground based laser system. Defensive systems include a space interdiction net capable of detecting and intercepting satellite signals and miniature satellite body guards to protect high–value space assets. These systems will form the backbone of systems which should be pursued in order to ensure US space superiority in 2025.

Chapter 1

Introduction

The year is 2025. Somewhere in a low-earth orbit, a US–owned communications satellite, one of dozens, quietly and unexpectedly goes off the air. Ground controllers with their extensive computerized control systems are puzzled but surprisingly not alarmed. They should be.

Unknown to them, or to the United States (US) defense community, a consortium of rogue nation-states and organized crime cartels has just tested their new, hi-tech satellite blanker. The threat to the single satellite is formidable. The threat to US national security will be devastating when these satellite blankers can target multiple satellites simultaneously. This nightmare happens less than a year later. In an unexpectedly swift and decisive move, links to US military forces worldwide are cut, global positioning system (GPS) navigation is virtually nonexistent, and a majority of US commercial and military reconnaissance returns are nothing but static. Unfortunately, US counterspace capabilities failed in this fictional glimpse into the future.

This paper's purpose is to demonstrate the need for, and the means by which, counterspace operations will be conducted in year 2025. The future, specifically by the year 2025, will see many nations capitalizing on the vantage point of space for both commercial and military reasons. The US will continue its growing reliance on military and commercial space-based capabilities. To protect those capabilities and, when necessary, deny similar capabilities to adversaries, the US must be able to conduct counterspace operations to achieve space superiority.

In building the case for counterspace operations, we make no limiting assumptions. We expect space will be as open and accessible in 2025 as air travel is today through international airspace. The pervasive nature of space assets will foster the broad use of space by most of the nations of the world. Protecting the

use of space and controlling, when required, its omnipresent potential advantages is the essence of counterspace.

This paper first frames the counterspace challenge by emphasizing the urgent and compelling need for a counterspace capability in the 2025 time frame. The discussion then turns to the road to weapons in space and the current proliferation of space capabilities today. Next, we describe counterspace system concepts that will add credibility and substance to future US counterspace operations. These concepts are organized within five technology categories:—(1) space detection and targeting, (2) miniaturization, (3) space stealth, (4) kinetic energy weapons, and, (5) directed energy weapons. Some concepts stretch the imagination but undoubtedly will lay a foundation for what the future space fleet should look like. Next, the concepts are woven into a space defense network to illustrate a system connectivity and concept of operations. Finally, the paper makes some investigative recommendations for future procurement and technology assessments.

Chapter 2

Framing The Challenge

Space superiority will be a key pillar in the war–fighting doctrine of the future. In developing joint doctrine for the twenty–first century, the Joint Warfighting Center (JWC) emphasizes the integration of three capabilities—precision engagement, battlespace awareness, and enhanced Command, Control, Communications, Computers, and Intelligence (C^4I)—to form a "system of systems."[1]

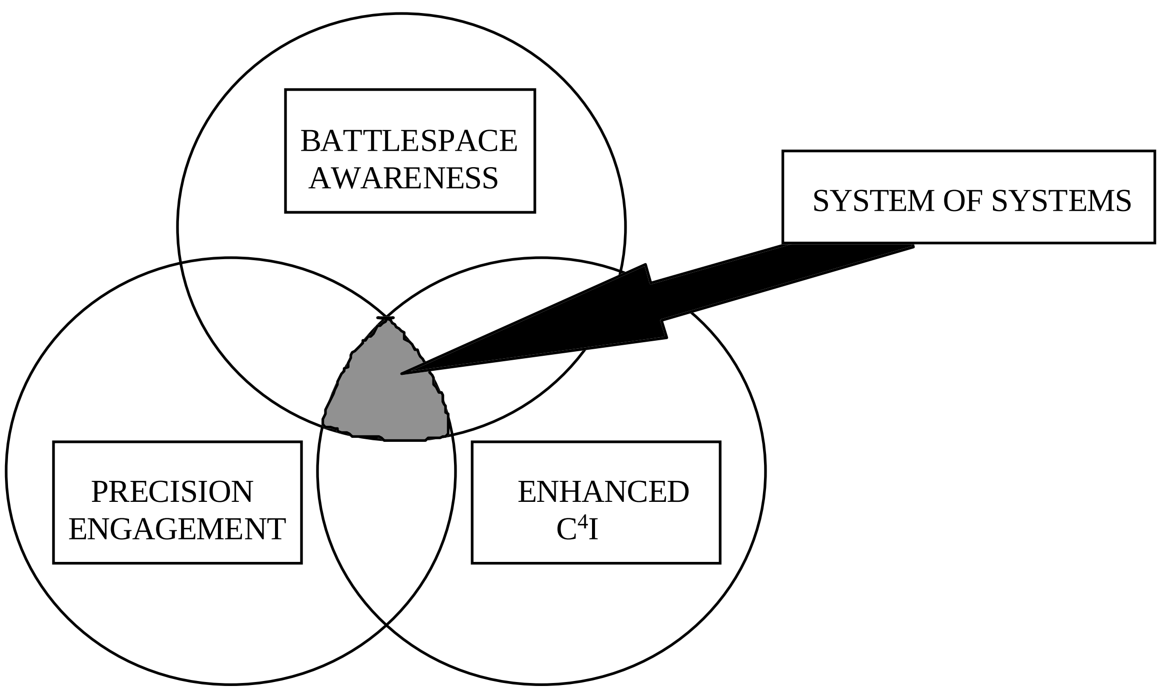

Figure 2-1. Joint War–fighting 2010: A "System of Systems."

The combined effects of such future capabilities as sensor-to-shooter linkage, real–time situational awareness, precise knowledge of the enemy, exponential increases in data processing, and modern command and control systems will increase US destructive effectiveness above that of any competitor.

In the 2025 time frame, each of these capabilities could be performed solely from space, or, if not, will rely heavily on space systems. Battlespace awareness will be gained through spaceborne intelligence gathered in all spectra to turn battlespace awareness into knowledge. Battlespace awareness also includes information warfare. In a world heavily reliant on satellite communications, space will be a critical battlefield in any enemy's information war. Enhanced C^4I will rely on space technology to identify important targets, handle data provided by the expansion of sensors, and transfer information to the weapons or forces best suited for the engagement. Precision engagement will invariably be dependent upon enhanced satellite global positioning data, space assisted targeting capabilities, and satellite communications to tell the shooter where to put bombs on target. This type of war–fighting framework will rely heavily on space capabilities. Because of this growing reliance on space, a vigorous counterspace capability will be required to protect US capabilities and deny the enemy any advantage to be gained from the employment of their space assets.

Space as a Vital National Interest

In order to understand the importance of counterspace operations to the air and space environment in 2025, it is important to identify why space will be important to our US national interests. In addition to its role as a key enabler of future joint war–fighting doctrine, counterspace capabilities will be driven by three other significant factors in 2025. First, space will contain interests vital to US national security. Second, the US will continue to look at the freedom to operate in space just as we look at the freedom to operate in international airspace or international waters today. Third, the US will depend on unimpeded space operations for achieving information dominance.

Traditionally, the US has gone to war over only those most critical issues deemed vital interests. Historically, space has never been seen to contain such vital interests. US space systems have not yet been attacked. However, the evolution of space as a strategic necessity in the protection of US vital interests will very likely make space assets themselves vital to the protection of US sovereignty. The compelling question is: Will the US consider it an act of war if a critical space asset is intentionally degraded or destroyed in the

future? As a point of comparison, Soviet space strategy envisioned space as an extension of the terrestrial and maritime battlefield.[2] As a result, any attack on their space–based warning system is a threat to which armed force, including nuclear force (if coupled with other signs of preemployment or preparation) might be the reply.[3] If the destruction of a satellite or its command and control segment leads to the loss of American lives, this should be seen no differently than the shootdown of a C-17 loaded with airborne troops. Another scenario is one in which space-based intelligence, degraded by an enemy, causes the Federal Bureau of Investigation to fail to stop a terrorist bombing which might have been avoided with unspoiled space–based information. Will this be tolerated in 2025? The ramifications of a failure to achieve and maintain space superiority are far reaching to the civilian as well as the military population.

Gen Charles Horner, former commander in chief, United Space Command, envisioned his worst nightmare as seeing an entire Marine battalion wiped out on some foreign landing zone because he was unable to deny the enemy intelligence and imagery garnered from space assets.[4] Horner emphasized the need to operate our own space systems while developing and deploying the capability to negate an adversary's use of space to support hostile military or terrorist forces. The means to accomplish these goals lie in the ability to perform the counterspace mission. Options for space system negation are bounded only by methods available to attack an enemy. Hard kill can be accomplished by directly targeting the satellite with kinetic or directed energy weapons or by attacking ground–based control facilities or launch sites. Soft kill methods include jamming or intruding the satellite signal or targeting the communication links or ground stations.[5]

In addition to protecting our satellites and denying the enemy the ability to use space against us, the US must preserve its freedom of action in space. In a future where space is equivalent to international airways or seaways of today, the US must be able exercise an equivalent freedom of passage in space. This includes operating military and commercial satellites when and where they are needed. The increasing impact of space systems on military, political, and economic policy make the freedom to operate in this medium critical to US prosperity. Commercial interests using space today range from global telecommunications to global positioning. Ultimately, ensuring freedom of navigation to friends and allies will serve to enhance US prestige abroad in support of national security objectives. This will require the ability, through force if necessary, to assure friendly space assets the ability to freely operate in space.

Space superiority, gained and maintained through offensive and defensive counterspace actions, supports the concept of information dominance. The main product of space systems is information. From communications to imagery, weather, or remote sensing, satellites provide information which today is used by a broad spectrum of clients. Identified as a significant part of the battlefield of the future, information warfare may be a new type of strategic warfare.[6] In the future, space will be inextricably tied to information and thus information warfare. Information dominance can mean the difference between success and failure of diplomatic initiatives, successful crisis resolution or war, or forfeiture of the element of surprise. Therefore, the ability to attain information dominance can widen the gap between friendly actions and enemy reactions. On the other hand, failure to achieve information dominance at the onset of hostilities could lead to the inability of friendly forces to conduct military operations successfully.[7] While this paper does not go into any further discussion of information warfare, it seeks to point out the value of space assets (and therefore vigorous counterspace actions) to achieving information dominance in the future.

In order to protect vital interests in space, ensure freedom of space navigation, and achieve information dominance, the US will eventually require weapons in space. The need to counter future space threats and minimize US space vulnerabilities will drive the American people to accept the inevitable—weapons in space. A discussion of the political, policy, and treaty ramifications of weapons in space will highlight some of the existing hurdles to such a venture.

The Road to Weapons in Space

This paper proposes that by year 2025 the US, and indeed the world, will be so reliant on space systems that space superiority will be of vital importance. This in turn will require the placement of force application weapon systems in space for defense against attack and to carry out offensive actions as necessary. Many futurists, both military and civilian, have hailed the rapid development of technology and have predicted the placement of weapons in space. Many say it is inevitable. There is, however, much more to this question than technological capabilities or some kind of intuitive sense of destiny. It is a significant leap from the current political mindset about space use, to a new mindset which supports placing force application platforms in space. The obstacles to placing weapons in space lie in the following three general areas which are not mutually exclusive: international space treaties, policy, and the space sanctuary illusion.

So the question remains, What will be the road to weapons in space? What preconditions will be necessary in the areas of treaties, politics, policy, and social perspective that will lead our military and political leaders to actually break that self-imposed, invisible boundary? There are several treaties which deal with various aspects of military space activities. These include the Limited Test Ban Treaty (1963), the Outer Space Treaty of 1967, and the Antiballistic Missile (ABM) Treaty (1972). The only specific prohibition to weapons in space deals with weapons of mass destruction.[8] The current administration has been negotiating with Russia on modifying the ABM Treaty, which prohibits space-based ABM systems, in order to allow for development and deployment of more capable theater missile defense. Some say the ABM Treaty is a product of the cold war whose time has past. Others say the US should just abrogate it outright. Many are now talking about changing the treaty or abandoning it altogether. It seems possible that the ABM Treaty is on the verge of significant change which may remove one of the main treaty obstacles to force application in space.

With respect to national policy, we have come a long way from Dwight D. Eisenhower's fundamental principles that US space activity would be devoted to peaceful purposes for the benefit of all mankind. More recently, President George H. Bush's policy specified defense against enemy space attack and assuring freedom of action in space.[9] One could certainly argue that based on the changes in national policy, an important part of the "road" has already been traveled. Having a national policy that calls for force application from space is a good place to start. The problem is policy is meaningless if the nation's leaders lack the will to implement it or support those who try to implement it. Our national politicians need to recognize the critical nature of space systems, space vulnerabilities, and the need to support pursuing space control and force application capabilities in space. This awakening must occur before a crisis arises and before an antagonistic nation either attacks or deploys the capability to destroy US space assets and holds the nation hostage. Shifts in political will may be forming today as the Congress has been trying to pass legislation to deploy a national missile defense system.

Public will is another matter and is something infinitely difficult to assess. Focusing closer to home, the American people must be asked, "Are you comfortable with the idea that some rogue nation is able to destroy both military and civilian satellites causing you to lose your cable TV, your cellular phone, and the navigation system that guides you to your favorite fishing hole." All things considered, it seems reasonable to

predict by 2025 the US will have mustered the political and social will, in recognition of the absolute criticality of assured freedom of operation in space, to get over the sanctuary hurdle and place the necessary space force structure in place.

The Growing Need for Counterspace Capability

In order to understand why a counterspace capability will be critical in 2025, it is only necessary to look at recent developments which point to the explosive growth in usage of space assets worldwide. As both commercial needs and military missions are increasingly met via space systems, the ability to protect the sovereignty of US and friendly satellites will grow in importance. Make no mistake—there is a potential threat. With the intent to "deny the use of outer space to other states," the former Soviet Union developed and tested anti-satellite (ASAT) weapons in the 1960s and 1970s.[10] Moreover, a stated high–priority Soviet objective in the late 1980s was a space–based high–energy laser ASAT weapon to complement their current ASAT capable systems.[11] Based on these developments, it is reasonable to assert that a number of nations will develop an ASAT capability over the next 30 years.

Proliferation of Access to Space Systems

United States. The US is critically dependent on space. Communication, navigation, intelligence gathering, and weather observation are just a few of the areas in which the US has leveraged its future into space. This investment vigor extends to the commercial arena as well. Numerous domestic and international businesses have committed large sums of capital in order to deliver products and services to the customer. According to the *New World Vistas: "Space Applications Volume*," in the commercial telecommunications area alone, six different constellations will become operational in the late 1990s.[12]

Table 1

Proposed LEO Communications Systems.

	COMPANY	# SATELLITES	ORBIT/ INCLINATION	COST	IOC
TELEDESIC	MICROSOFT/MCCAW	900 (40+4 IN EACH PLANE)	21 PLANES 98.2 DEG SUN SYNC	$15B	2001
IRIDIUM	MOTOROLA, LOCKHEED	66 (+ 7 SPARES)	6 PLANES/ 11 EACH	$3.4B	1994
GLOBAL STAR	LORAL, QUALCOM & SPACE SYS	48 (6x8) +8 SPARES	8 PLANES 52 DEG	$1.8B	1997
ELLIPSO	ELLIPSAT CORP/ WESTINGHOUSE FAIRCHILD	14-18	ELLIPTICAL 63.4 DEG	$650M	1998 (?)
ODYSSEY	TRW	12-15	55 DEG 3 PLANES 4 SAT	$1.3B	1999
ARIES (FORMERLY)	CONSTELLATION COM, INC. & DEFENSE SYSTEMS	48 (4x12)	4 PLANES CIRCULAR	$300M	1994

Source: USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century* (unpublished draft, the space applications volume, 15 December 1995), 7.

In addition to the explosive commercial growth in space, the military continues to press the strategic advantage that control of the space domain offers. Desert Storm can arguably be designated the "First Space War." From weather forecasting to target intelligence, US success relied heavily on spaceborne systems. National assets, combined with our GPS constellation, increased the accuracy of our forces, both in, and out of the Kuwait/Iraq theater. The defense satellite program (DSP) system provided tactical warning of Scud launches within minutes, enabling our defense forces to come to their highest alert and defeat the threat. More so than in any past conflict, connectivity between the fielded forces and the commander make information and decisions instantly available to the one who needed it most—the war fighter. As the US depends more and more on precision as a force multiplier, the ability to detect, identify, and target threats will become paramount. To counter increasingly mobile enemy forces, this ability needs to be either real time or near real time. Space offers a medium for near instantaneous, cheap communications. It offers the possibility of continuous surveillance plus highly accurate positioning. In Jeffery Barnett's book, *Future War,* he called these "war-deciding capabilities."[13] As such, our space capabilities must be protected and the enemy's capability must be negated.

The "Rest" of the World. Other economic and military powers also recognize the value of space. The European Community, the Commonwealth of Independent States, Japan, and China, just to name a few, all have active launch programs deploying assets into space. While our future quarrel may not be with the

“owner” of the space asset, the enemy’s ability to access the information could be very detrimental to our cause. Even in 1991 the “CNN factor” was significant. Saddam Hussein certainly had his television on, even if he could not talk to his troops.

The Teal Group Corporation, a defense and aerospace analysis firm, identified 949 spacecraft that have been funded or scheduled for launch from 1995 to 2004.[14] It is likely that the end of defense export restrictions on sales of computers will allow many countries to manipulate, store, and disseminate medium-resolution data, such as that offered by satellite positioning and tracking (SPOT) and LANDSAT, and make the imagery vastly more useful to foreign militaries. By encouraging US concerns to become commercial leaders in selling imagery as fine as one meter resolution, the government hopes to discourage many other nations from developing their own systems or buying services elsewhere.[15]

These current capabilities, demonstrated by multiple countries, are a loud warning to the US to maintain its edge in space technology. Improved capability can be expected in the future. The increase in satellite information vendors means organizations without space capability can purchase the end product from a wide variety of sources.

System Vulnerabilities in 2025

Most, if not all, space systems have three segments: space, ground, and user. Using a communication satellite system as an example, the space segment is the actual satellite. The ground segment likely consists of one or more stations that control customer access to the satellite. The user segment is the customer, the person who is trying to communicate, as well as any user equipment.

Each segment has its own vulnerabilities in a combat environment. Capabilities described later in this paper may make satellites the most lucrative targets to attack, while the political situation may make such an attack untenable. The US may be able to strike a satellite system because it is supplying a third country with intelligence, but unwilling to do so because we are engaged in talks of a delicate nature over a separate issue. Using the same rationale, the ground segment may be too politically sensitive because of its location. In reality, the user segment may be the most politically acceptable target, but it is practically invulnerable due to its dispersed nature.

Existing US technology can strike all segments of space assets. Demonstrated F-15 (ASATs) takes low–earth–orbit systems targets today.[16] Extensions of this, and other technologies discussed later, will make medium earth orbit and high earth orbit systems vulnerable in 2025. Ground and user segments today are vulnerable to both conventional and nonconventional attack.

Threats to Space Systems in 2025

There will be multiple threats to space–based systems in the future. Some will involve threats to the space segment, some the ground, and some the user. These threats could or will come from current conventional forces, space–based forces, or other advanced technology ground/air forces. These threats can be extensions of today's technology, such as F-15 ASAT derivatives or the detonation of nuclear weapons in space. Another possibility will result from leaps in technology that enable realistic directed energy, kinetic energy, and electromagnetic pulse (EMP) based weapons to be directed to individual targets.

To this point, the discussion has focused on the need for counterspace capabilities in 2025 and the challenges facing US forces in gaining and maintaining space superiority. The next section describes key technology areas, ranging from space detection and targeting to directed energy weapons, as well as specific concepts and capabilities, which will enable US commanders to absolutely control the high ground in 2025.

NOTES

[1] Joint Warfighting Center Doctrine Division, *Warfighting Vision 2010 (Draft)* (Fort Monroe, Va.: 1995), 10.

[2] Gen John L. Piotrowski, "A Soviet Space Strategy," *Strategic Review*, Fall 1987, 56.

[3] Ibid., 57.

[4] Prepared statements of Gen Charles Horner, commander in chief, United States Space Command, in Senate, *Space Seen as Challenge, Military's Final Frontier* (Defense Issues, Prepared Statement to Hearings before the Senate Armed Services Committee, 90th Cong., 1 sess., 1993), 7.

[5] Ibid.

[6] Barry R. Schneider, "Battlefield of the Future," *The Revolution in Military Affairs* (Maxwell AFB, Ala.: Air University Press, 1995), 80.

[7] Maj James G. Lee, *Counterspace Operations for Information Dominance* (Maxwell AFB, Ala.: Air University Press, 1995), 4.

[8] AU-18. *Space Handbook*. Vol. 1, *A Warfighter's Guide to Space* (Maxwell AFB, Ala.: Air University Press, 1993), 55–56.

[9] Ibid., 103.

[10] Nicholas L. Johnson, *Soviet Military Strategy in Space* (New York: WW Norton and Co., 1986), 155.

[11] Capt Gregory C. Radabaugh, "Soviet Antisatellite Capabilities," *Signal*, December 1988, 81–83.

[12] USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century* (unpublished draft, the space applications volume, 15 December 1995), 7.

[13] Jeffery R. Barnett, *Future War, An Assessment of Aerospace Campaigns in 2010* (Maxwell AFB, AL: Air University Press, 1996), 41.

[14] James R. Asker, "Space Control," *Aviation Week & Space Technology*, 23 May 1994, 57.

[15] Ibid., 51.

[16] While the technology demonstration program validated the concept, F-15 ASAT missiles and warheads were not maintained after cancellation of the program.

Chapter 3

Key Technologies And System Descriptions

Space Detection and Targeting

General Discussion. The linchpin in delivering a critical blow to an enemy system anywhere in the expanse of the air and space environment is accurate detection and targeting. This capability is crucial in providing total battlespace situational awareness. To make this happen, significant advances are required in radar, laser, and infrared detecting and tracking technologies. While "detecting and targeting" imply offensive capabilities, they also lead to formidable defensive capabilities in countering enemy kinetic energy weapon (KEW) and directed energy weapon (DEW) attack.

In order to defend against an ASAT, for example, the defending satellite (or its controlling system) must be able to detect approaching threats in order to defensively react. Defensive traits must go beyond today's satellite hardening and limited space maneuvering. In 2025, space systems must be able to organically detect intruders, have built–in stealth characteristics, and if needed, be able to actively defend against attack. The following concepts explore some system possibilities intended to give the space force commander dominant battlespace awareness.

Gravity Gradiometer

System Description. Gravity gradiometers are instruments and systems that detect mass density contrasts. Recent gravity gradiometer research has focused on sea-based submarine detection applications. [1] This concept goes several leaps forward and proposes its use in space as a passive detection system.

Concept of Operations. With multiple gravity gradiometers located on multiple satellites in orbit, approaching "foreign bodies" can be passively detected. Data and measurements gathered could be combined with data from other detection devices in Kalman filtering or data fusion algorithms to enhance detection and even identification probabilities.

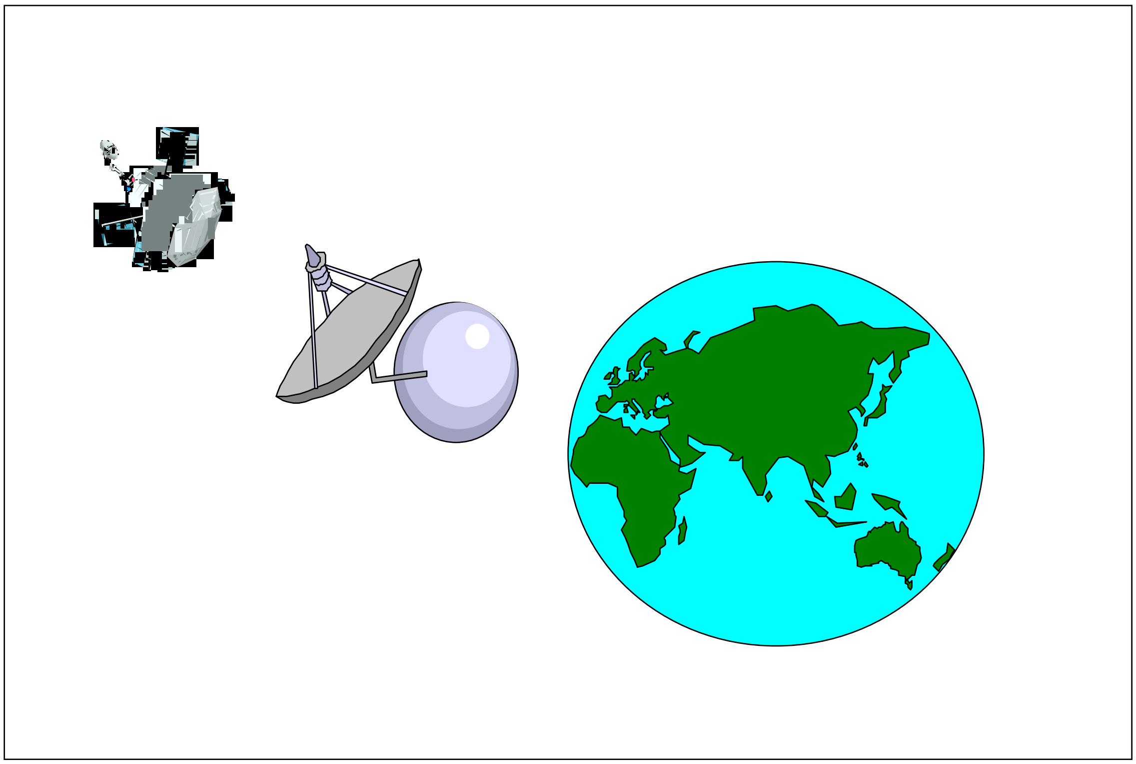

Figure 3-1. Gravity Gradiometer

Gravity gradiometers embedded in multipurpose satellites or spacecraft will detect approaching bodies. Multiple gradiometer systems can accurately pinpoint foreign body locations for follow-on defensive reactions.

Four critical subtechnologies are identified for feasibility investigations with gravity gradiometers. These are (1) gravity gradiometer technology itself; (2) advanced filtering algorithms to combine data from other sensors to enhance detection, location, and identification of approaching bodies; (3) modeling capabilities to appropriately model gravity gradiometer errors and signals; and (4) simulation capabilities to determine the gravity gradiometer accuracy required as a function of the size and mass distribution of the

body under scrutiny, as well as its proximity and maneuver pattern. In order to be able to use the gravity gradiometer in a space detection mode, technology advances must yield a system, which can be deployed in space, capable of detecting an object on the order of 100 kilograms at a range of 100 nautical miles. Reaching this sensitivity by 2025 is an extreme challenge and may be a limiting factor in fielding this technology.

Countermeasures. Synthetic gravity fields may provide effective countermeasures to gravity gradiometer systems. However, the technological leap to "produce" gravity is formidable and not likely by the year 2025. Nonetheless, combining data from other sensors (space based or ground based) to validate organic gravity gradiometer inputs would counter synthetic gravity deceptive attempts.

Anti-ASAT System

System Description. The Anti-ASAT system incorporates a host of sensors embedded on orbiting satellites or spacecraft combined with an artificial intelligence program to detect approaching bodies. [2] Sensors will detect all forms of radiated wave energy (IR, RF, electromagnetic, etc.). Additionally, the concept design includes ablative and reflective coatings on the host satellite for defense against directed energy attack.

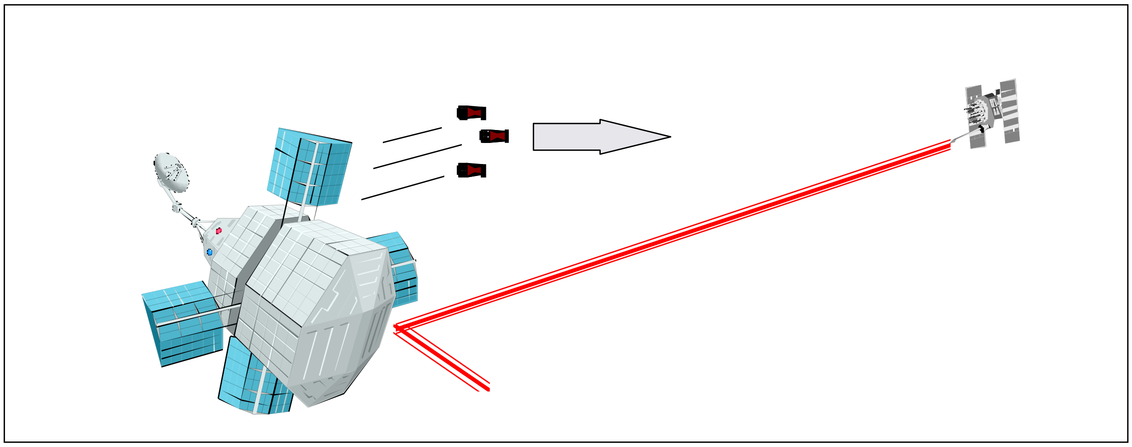

Figure 3-2. Anti-ASAT System

Concept of Operations. This is a satellite self–protection system. If the satellite or spacecraft is approached or attacked by external threats, onboard protective systems eject matchbox-sized "defenders" to home on the intruder, attach to it, and disable it with shaped charges or degrade it by leaching power or disrupting uplink/downlink commands. Hypothetical design should provide a probability of survival (P_S) of .7 against co-orbital threats, .4 against impact or ASATs, and .25 against energy beams. When placed on stealthy satellites, a measure of stealthiness is lost although P_S increases to .9 against co-orbital ASATs and .6 for impact or ASATs and energy beams.[3]

Countermeasures. An overwhelming attack could defeat the system's self–protection capabilities and destroy or degrade the satellite.

Space Interdiction Net

System Description. Key to any counterspace operation in the future will be total battlespace awareness. The purpose of the space interdiction net is to detect satellite transmissions, identify the source of those transmissions, and find the end user of the information.[4] This capability is required in order to selectively deny information to an adversary from his own military satellite system or a commercial system. In addition, a space interdiction net will be used to determine whether damage to US or friendly satellites is a result of malicious action or natural causes, such as solar flare or asteroid collision. Consisting of an orbiting grid of satellites capable of continuous coverage of the earth, the space interdiction net will use a web of interlinked microsat systems to radiate a very low power force field over the globe. The field generated by the constellation will act as a blanket around the earth and will be able to detect any energy penetrating the blanket, seek out the desired signal, and jam or degrade that portion of the signal which is important. This force field will be capable of picking up transmissions in a wide range of frequencies and will use triangulation from three or more satellites to pinpoint the source. A capability to detect 70 percent of the transmissions will probably be attainable in 2025. All data deemed not critical to enemy hostile action is left alone to be received as originated. This selectivity enables US commanders to take positive military action to deny an enemy critical information without disrupting nonmilitary information traffic.

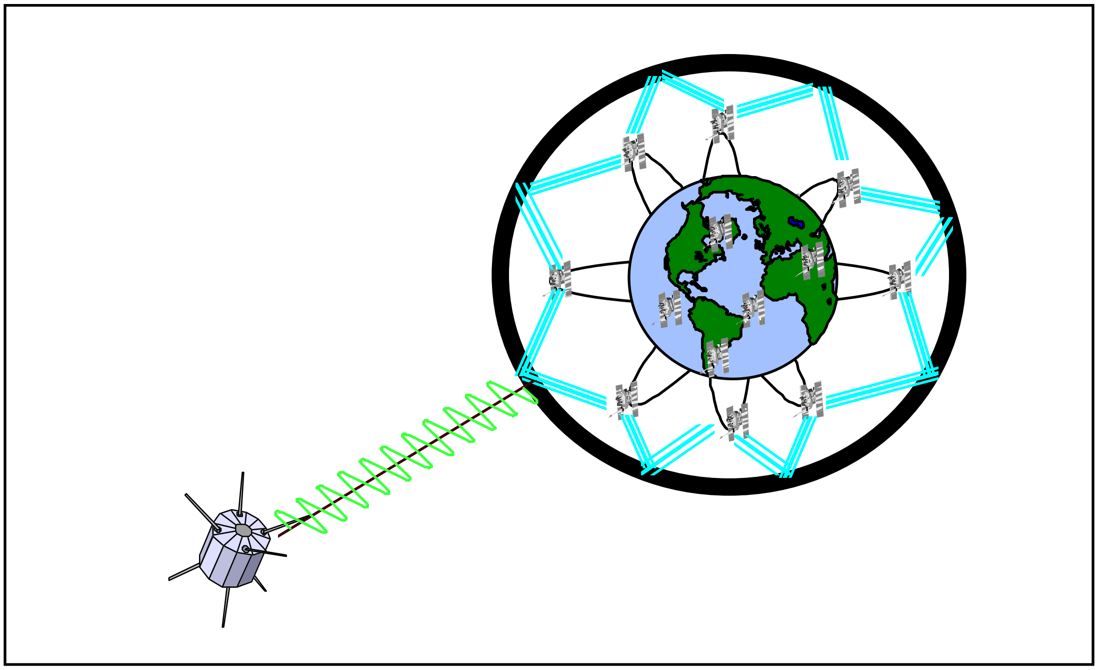

Figure 3-3. Space Interdiction Net.

In 2025, the number of satellites orbiting the earth will rise dramatically (increasing by 25 percent between 1999 and 2005)[5] and commercial systems will form the backbone of the space information network. The key to performing counterspace operations in this environment will be the ability to identify the critical information being transmitted to an enemy. Upon detection of hostile satellite signals, the interdiction grid will be able to deploy a number of countermeasures ranging from jamming and electronic warfare to destruction via kinetic or directed energy weapons. These actions ultimately keep the end user from capitalizing on critical information from his spaceborne assets.

From a technology standpoint, the power source for this system of integrated sensor network is the most daunting challenge. Battery technology may not advance enough by 2025 to provide continuous power to the system. Solar power can be used a majority of the time, but battery technology is still required for times when sensors are out of view of the sun. A possibility is to use a thin film reflector on orbit to light solar cells on the sensor satellites as they orbit in the shadow of the earth (see the solar optical weapon concept presented later in this paper).

As shown by a variety of concepts presented in this paper, there are a wide variety of ways to disrupt, deny, degrade, or destroy satellite transmissions at the source. However, these methods are not selective in

that they deny information to all users. The detection and interdiction system will be capable of specifically identifying only that information which is being used against the US or its allies. This information can then be used by field commanders and the national command authorities (NCA) to determine whether or not to take action against the satellite itself or its owners. In many cases, the "owners" will be known, as in the case of multinational corporations who operate satellites as part of their business infrastructure. Again, the spectrum of options ranges from soft kill to hard kill.

Another particularly interesting possibility is the modification of the ionosphere to disrupt communications. A number of methods, such as chemical vapor injection and heating or charging via electromagnetic radiation or particle beams, have been proposed to modify the ionosphere.[6] Because ionospheric properties directly affect high–frequency communications, an artificially created ionization region could conceivably disrupt an enemy's electromagnetic transmissions. Offensive interference of this kind would likely be indistinguishable from naturally occurring space weather. The capability to create ionization regions could also be used to detect and precisely locate the source of transmissions.

In order to interdict specific signals, the space interdiction net will be capable of projecting a force field between the target and the receiver. This force field will be in the form of a magnetic field or charged particle cloud. Another possible means of surgically removing specific transmissions is a precision molecular particle which, using a nanotech computer brain, follows the data stream to the source. Once at the origination point, the smart particle destroys the frequency bandwidth on which the critical data is being transmitted. We recognize that technology to dissect transmissions at the molecular particle level may not be achieved by 2025 but once achieved will add dramatic leap in counterspace capabilities.

This concept relies on a tightly integrated net of satellites operating in low earth orbit (LEO). The system must be placed in a roughly 250–300 nautical mile orbit in order to be able to detect transmissions from major orbital regions from low earth to geosynchronous. In order to provide continuous coverage to all points on earth, the system will consist of three interlinked constellations of 66 satellites for a total of 198 satellites. All satellites will be interlinked with each individual satellite capable of assuming control of a "hot" sector, one in which hostile transmissions are detected. Satellites will consist of a power system and phased array antenna to project the low energy detection field. In addition, a very high–speed computer will integrate the incoming detection data and correlate the data to a source through triangulation. Finally, a

directional antenna, on order from the command and control subsystem, will project a controlled cloud of charged particles to a point in the sky. The end result is a large charged particle cloud or ionization region placed precisely between the sender and receiver. A further leap would use molecular sensors and computers to lead individual molecules in the charged particle cloud to seek out and destroy specific bits of information from the data stream. The idea of surgical strike has now been taken to the molecular level.

The limiting factor in making the space interdiction net a reality will be the ability to project low power fields over large areas in space. A number of evolutionary advances in space weather forecasting and observation are required to make ionospheric exploitation a reality. The high–speed computer technology necessary to control the smart particles should be available in 2025. In addition, nanotechnology computers may make possible the development of smart charged particles which will be capable of finding and destroying signals. The combination of very low orbits (prone to orbital decay) and the high number of satellites required to form the system will drive the need for a very high resupply rate. This in turn points to the need for a very robust launch capability.

Concept of Operations. The space interdiction net will be in constant orbit around the earth. The system will monitor space transmissions continually while especially looking for strategic indicators which may be warning of impending escalation. With the capability to perform selective offensive counterspace, the activation of the system itself can act as a deterrent to further aggression. Intelligence inputs will give the system an initial estimate of enemy space capabilities which will enable the detection and interdiction system to focus on certain satellite constellations.

The grid will be capable of interrupting key information from all types of satellites including communication satellites, imagery satellites, and weather satellites. It will be closely integrated with the C^4I system to allow commanders at all levels near instant data on which enemy capabilities have been negated. In addition, the grid will be linked to the other assets which makeup the counterspace system. If precision signal blocking is not necessary, alternate counterspace systems such as directed energy or parasite microsatellites (described later as robo-bugs) can be employed to disrupt or destroy the enemy's space capability. In order to ensure the grid is constantly maintained, a number of on–orbit spares will be placed in parking orbits to be used as needed. A quick-turn launch capability is required to keep the system operationally ready due to expected orbital decay of the LEO satellites which makeup the system. The

interdiction net must be capable of integrating with the command and control system as well as the intelligence system.

Countermeasures. An important countermeasure to this type of system lies in the ability to disrupt or create holes in the detection field. Encryption methods may be capable of making signals hard to attack with smart molecular munitions. If the sender can disguise transmissions or make them capable of changing while en route to the receiver, it will be difficult to identify and attack the right data. Maybe the simplest way to defeat this type of system would be through redundancy via the proliferation of small satellites capable of performing specific missions. Thus, if one system is detected and jammed by the interdiction net, the mission can be accomplished by any number of other satellites capable of transmitting the critical information. This method also complicates the ability to target systems by increasing the cost associated with disrupting or negating a large number of miniature systems operating over a vast battlespace. Should ionospheric disruption become a reality, it could be turned against the space interdiction net to disrupt the low power field or interrupt essential command and control functions.

Miniaturization

General Discussion. Miniaturization is about the age old quest to do more with less, in military parlance, to package more capability in a smaller package. In space, the main reason for miniaturization is weight savings—the ability to maximize precious spacelift resources. This in turn reduces the cost of space systems. Another reason for miniaturization in space is redundancy. A constellation of small satellites performing parcels of the mission is not so vulnerable as a mega-satellite tasked with doing it all. Finally, miniaturization in space opens up new avenues to exploit enemy space systems. It is in this realm that miniaturization can make a true contribution to the counterspace mission. Of note is the urgent desire for commercial industry to exploit miniaturization. Dr Tom Velez, in the keynote address at the eighth annual American Institute of Aeronautics and Astronautics (AIAA) conference on small satellites noted that the small satellite or "smallsat" industry is growing "for reasons that are not political, not military, not scientific, but commercial . . . they're cheaper and more capable of providing user services."[7] This commercial interest should aid immeasurably in the development of technologies and systems that will enable a robust counterspace capability in 2025.

The electronics industry has shown the ability to double the number of transistors on a microchip every 18 months. This trend has driven a dramatic revolution in electronics. Researchers note that the ability to "manufacture millions of microscopic elements in an area no larger than a postage stamp" has inspired further miniaturization technology.[8]

Two emerging technologies show particular promise in making spacecraft smaller and more capable. The first, microtechnology, is the combination of miniaturized mechanical and electric components in microelectromechanical systems (MEMS). The Scientific Advisory Board's *New World Vistas Space Technology Volume,* report labels MEMS as the next step in the microelectronics revolution in which multiple functions are integrated on a microchip.[9] An example of a future MEMS system is on-chip optics which will be used to provide agile target recognition and tracking.

The second technology, nanotechnology, is not nearly as developed. Its chief proponent, Eric Drexler, describes it as "taking what we're very familiar with on a macroscopic level and doing that on a vastly smaller scale using the basic building blocks of matter."[10] Drexler notes that instead of taking something large, like a silicon wafer, and making it small, nanotechnology starts with molecules and atoms and builds up in tinkertoy fashion. The results will go far beyond simply making atom-scale computers. The *New World Vistas Materials Volume* report notes nanobased processing could provide advanced electro-optical materials, molecular scale sensors, and dynamic stealth materials.[11]

Nanotechnology offers the capability to build molecule-size factories capable of churning out thousands of specialized nanomachines. Researchers estimate that it will take 20 to 30 years to achieve practical nanotechnology results. The following section describes the link between advances in miniaturization and proposed systems to perform the counterspace mission. Two counterspace concepts with miniaturization as the key enabling technology are promising. Satellite bodyguards—fleets of small satellite sentries—will protect high value space assets. Robo-bugs—parasite microsatellites capable of operating on or near enemy satellites—will use jamming and electronic warfare methods to disrupt and degrade information transmitted from enemy space systems. A description of these potential systems along with a proposed concept of operations follows.

Satellite Bodyguards

System Description.[12] In the years 2000–2005, we can expect a rapid growth in the average number of payloads being launched annually.[13] The decades following that will probably see launch rates grow at a much steeper rate. In order to protect the vast number of high–value space assets orbiting in 2025, active defensive systems must be able to respond to a wide range of threats. One way to meet this challenge is to place a large fleet of satellite bodyguards in orbits containing critical US and allied satellites. The large number of satellites requiring protection will drive an equally large constellation of bodyguards capable of performing a wide variety of functions. The most efficient means of achieving such a goal is to pursue advances in miniaturization such as microtechnology and nanotechnology.

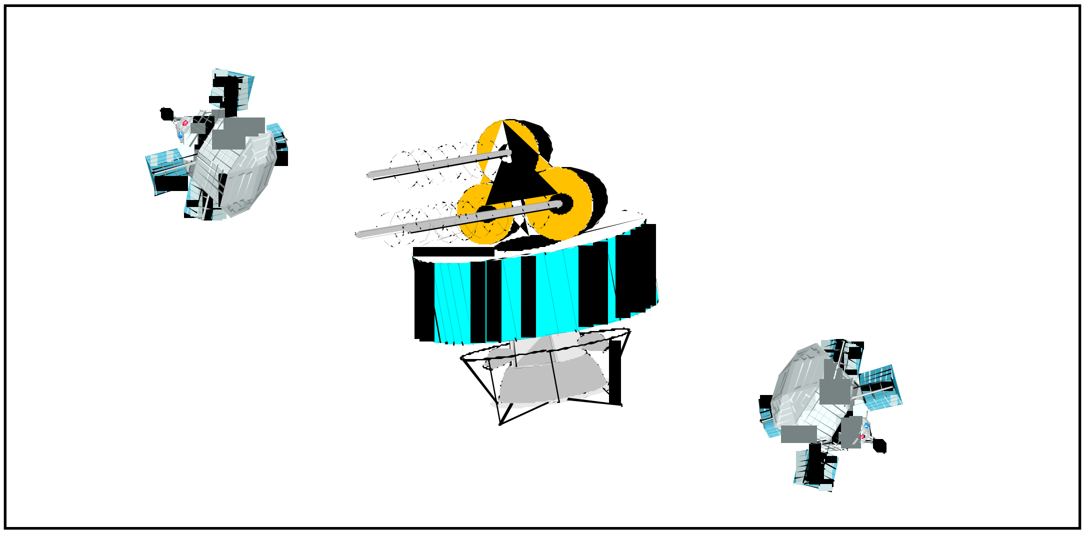

Figure 3-4. Satellite Bodyguards Protecting a High–Value Space Asset.

A space–based satellite bodyguard system might consist of an integrated network of orbiting microsatellites each performing specific subsets of the space protection mission. Similar to P-51 fighter aircrafts flying escort for B-17 bombers in World War II, this system of satellites will be required to detect enemy presence, determine the threat, and act to defeat the threat. However, the bodyguard system of 2025 must take this idea one step further and capitalize on miniaturization to make bodyguards weight and cost effective. The best way to accomplish this is through what Col Richard Szafranski and Dr Martin Libicki, air and space visionaries, call a meta-system.[14] A meta-system is composed of individual systems working

together to perform such tasks as information collection, battlespace awareness, and interfacing with other components of the cooperative distributed network.

Key components of any such meta-system will be miniature sensors coupled with high–speed computers to integrate inputs from multiple bodyguards. The sensor array (an integrated net of sensors on a number of distributed bodyguards) must be capable of detecting inbound threats operating in any spectrum including radar, infrared, acoustic, and visual. Current advances in smart materials and nanotechnology, as well as the miniaturization of high–speed computer technology, will make such a system feasible in the 2025 time frame. This is supported by the trends in computer chips which have gone from circuits three microns wide 10 years ago to current machines which are fabricated at the .35 micron level. Ralph Merckle of Xerox predicts the mainframe of the first or second decade of the twenty-first century "will be the size of a sugarcube and will execute more instructions per second than today's Cray supercomputers."[15]

While miniature high–speed computers and intelligent materials will increase the capabilities and staying power of the satellite bodyguard, advances must also be made in power and propulsion. Possible solutions to the power problem are nuclear batteries, advanced solar batteries, or fusion technologies, each resulting in a virtually inexhaustible fuel supply. Advances in nonchemical high specific impulse propulsion techniques may provide the revolutionary leap in propulsion needed to make a bodyguard capable of high–speed maneuvering (satellite jinking).[16]

A large fleet of bodyguards will be required to form a meta-system capable of protecting the growing number of high–value space assets, both military and commercial. This system, coupled with the need to launch large numbers of dispersed bodyguards in order to reduce the system's vulnerabilities, will make miniaturization a crucial technology in 2025. A robust space launch infrastructure as well as rapid resupply capability is necessary to keep a satellite bodyguard system operational in a high–tempo environment.

Concept of Operations. In applying the meta-system concept to a satellite bodyguard system, individual bodyguards the size of a laptop computer will perform unique subsets of the overall mission. Based on the same basic design, some bodyguards will be tasked as sensors with the mission to identify and track possible threats. Other bodyguards will be assigned a defensive role where their main function is to seek out threats and negate them. Taking this one step further, defensive bodyguards may be active or passive. Active defenders will use high–specific impulse propulsion techniques (such as electrostatic,

electrothermal, or electromagnetic systems which use electric power to accelerate propellant gasses to high exit velocities) to seek and destroy a space–based threat.[17] Passive defenders will use smart materials (capable of adapting to deflect or absorb inbound energy) to minimize electromagnetic or directed energy damage to a high–value asset. In a worst–case scenario, the bodyguard will sacrifice itself to protect the high–value asset it is guarding. Other bodyguards will be outfitted to perform critical computing and fire control functions.

For incoming ASAT missiles, the system may relay position, velocity, and acceleration data to an orbiting directed energy system which will make the kill. Another option is to equip bodyguards with satellite protective armor which would respond to a KEW attack much as today's reactive tank armor responds to antitank fire.[18] An alternate mission for a satellite bodyguard employs electronic warfare to confuse the enemy. Equipping bodyguards with electronic signals duplication capability will enable a bodyguard to replicate the electronic signature of a high–value asset.[19] By saturating the battlespace with large numbers of small and cheap bodyguards (which to enemy sensors appear to be high–value satellites), the problem of finding and destroying the truly critical satellite becomes much more difficult for an enemy.

Due to the high–risk mission they perform, satellite bodyguards will likely require steady replenishment through the logistics system. Self–replicating nanotech systems may aid in the rapid replacement of damaged bodyguards. A command and control link is assumed to be in place and is critical to the satellite bodyguard concept.

Countermeasures. One way to counter a satellite bodyguard system is to saturate the battlespace around the high–value system with threats to overwhelm the bodyguard meta-system. However, proliferation of inexpensive bodyguards performing subsets of the overall mission may make shooting them too expensive for a future adversary. The command and control function may represent the center of gravity of an integrated meta-system. Destroying the command and control link will effectively disable the bodyguard system by negating the critical integration of information between bodyguards. A hardened burst transmission send and receive capability will decrease the vulnerability of the communications link. Finally, the idea that visibility (to enemy sensors) may equate to death in 2025 makes emission control of vital importance to satellite bodyguards. Stealth as well as minimum communication requirements will help to make bodyguards more survivable in the battlespace of the future.

Robo-Bug

System Description.[20] In his 2,500–year–old classic *The Art of War*, Sun Tzu states that "all warfare is based on deception."[21] Those words continue to ring true today in the realm of space warfare. The idea of a robo-bug is to use small satellites, equipped with stealth or cloaking capability, to get close to a target enemy satellite. The robo-bug will then take on characteristics of the target. A plausible scenario has an undetected robo-bug satellite affixing itself to a navigation satellite similar to the Global positioning satellite (GPS). The robo-bug will have the capability to detect when a satellite is providing information to an adversary. At the right time, the robo-bug is activated and begins to disrupt the signal through jamming or other electronic warfare methods.

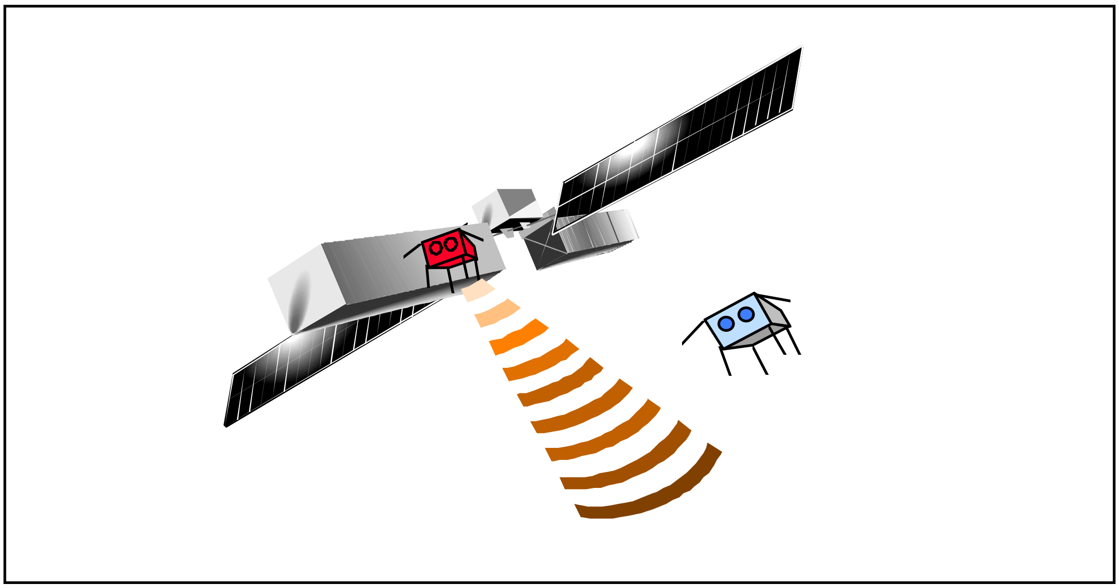

Figure 3-5. Robo-bug Microsats in Action.

Another option is to attack the link system, described as the electromagnetic energy used for space system uplink, downlink, or crosslink. Given a link segment made up of electromagnetic energy, the primary technology used to attack the link is electronic warfare in the way of jamming or spoofing. Jamming is transmitting a high–power electronic signal that causes the bit error in a satellite's uplink or downlink signals to increase, resulting in the satellite or ground station losing lock.[22] Spoofing involves taking over a space system by appearing as an authorized user. An example is establishing a command link with an enemy

satellite and sending anomalous commands to degrade its performance. Spoofing is one of the most discrete and deniable nonlethal methods available for offensive counterspace operations.[23]

In his work on counterspace options, Maj James Lee presents a number of options which can be used in an offensive counterspace mission against a peer competitor. These options target the entire system (ground, link, and orbital segments) and range from nonlethal disruption to hard kill as listed in table 2.[24] A robo-bug system will be capable of performing the entire spectrum of offensive counterspace options.

Table 2

Offensive Counterspace Options.

	PEACE	**CRISIS**	**WAR**
GROUND SEGMENT			- NONLETHAL WARFARE - STRATEGIC ATTACK -SPECIAL OPS
LINK SEGMENT	- LOCAL JAMMING UPLINK DOWNLINK	- LOCAL JAMMING UPLINK DOWNLINK - SPOOFING	- JAMMING UPLINK/DOWNLINK - SPOOFING
ORBITAL SEGMENT	- NONLETHAL DISRUPTION	- NONLETHAL DISRUPTION - MISSION KILL	- NONLETHAL DISRUPTION - HARD KILL/MISSION KILL

Source: Maj James G. Lee, *Counterspace Operations for Information Dominance* (Maxwell Air Force Base, Ala.: Air University Press, 1995),34.

The robo-bug is capable of destroying the enemy satellite with a shaped charge explosive or high energy event such as high–power electromagnetic pulse (EMP) or high–power microwave burst. An alternative, the ability to accomplish the counterspace mission with what General Horner, in a speech to the Senate Armed Services Committee on 22 April 1993 described as a "soft kill" (including jamming or intruding the satellite signal and communication links) enables US forces to deny an enemy use of space information without destroying satellites. In a future which sees a blurring of space missions between military, multinational corporations, and numerous governmental organizations, this capability will offer the commander a desirable option to be used in meeting a politically sensitive military objective—space superiority.

A robo-bug system will be comprised of a main module which will take care of basic needs such as power, navigation, and station keeping. The satellite itself will be built using stealth cloaking techniques (described later in this paper). The command and control system will be used to receive direction via

ground or space link and act upon that information to direct the robo-bug to its assigned target. The heart of the system will be the payload which will have a specific mission. Missions are discussed in the concept of operations. The emerging technologies which might make a robo-bug system feasible are MEMS technology, nanotechnology, and small high–speed computing. As previously discussed, each of these technologies show signs of being near maturity in the 2025 time frame.

Concept of Operations. The idea of a robo-bug is not to act as an antisatellite weapon. Instead, the robo-bug uses electronic warfare methods to negate a satellite's capabilities without permanent damage. Robo-bugs will be pressed into operation early in a potential conflict to degrade or eliminate the detection, imagery, and communications capabilities of an adversary.

Robo-bugs must operate in such a manner as to make any loss in enemy satellite fidelity very subtle so the likelihood of discovery by the operator is as small as possible. This can be done in a variety of ways. In addition to the spoofing mission as described in the navigation satellite example, another possible mission (forwarded by Gen Charles A. Horner) is jamming or intruding the satellite signal or targeting the satellite communication links. This negates the enemy's ability to maneuver the satellite or to deploy onboard systems such as sensors and antennas. Yet another possible mission is to simply act as a power drain, sapping the power from the enemy satellite much like a tick on a dog.

Countermeasures. In their paper "Tactical Deception in Air-Land Warfare," Charles Fowler and Robert Nesbit make a fundamental observation that "the military group that is not devoting appropriate efforts to include tactics, R&D, and plotting and scheming in general for deception is almost certain to be vulnerable to being deceived itself."[25] Any future US space system must be capable of defeating an enemy parasite system. Specific countermeasures to a robo-bug system are based on the ability to detect disruption efforts and take action. Assuming they can find a robo-bug, an enemy might do periodic maneuvers to avoid it or take offensive action to destroy it. Deception may also be an effective method of countering a robo-bug system. If a satellite is able to radiate emissions which make it appear to be nonthreatening (or even appear to be a friendly satellite), it may be able to fool a robo-bug.

Another very effective method in countering a parasite system is dispersion—using large numbers of small satellites to overwhelm detection and targeting systems. This method causes the enemy to expend numerous resources in an attempt to protect his valuable space systems. Once an enemy suspects a satellite is

being influenced by an unfriendly parasite, confirmation can be made by comparing data to known values. However, without a way to rid itself of the robo-bug, the satellite may very well be rendered useless. Once again, the command and control link between the commander and the robo-bug presents a vulnerability. The ability to operate in a secure command and control environment continues to be an essential part of any counterspace concept.

Space Stealth

General Discussion. Stealth conjures up images of a strike package of aircraft operating deep in enemy territory while the adversary waits, watches, and listens, all to no avail. Author J. Jones describes stealth as the act of proceeding furtively, secretly, or imperceptibly.[26] Fast forward the year to 2025 and imagine an enemy hunter-killer satellite team cruising right past a US command and control platform without the faintest hint of detection. Stealth, defined in terms of revolutionary molecular technologies, can be a key component in the protection of friendly space capabilities against enemy attack—classical defensive counterspace.

To date, numerous passive measures such as hardening, redundancy, and cross linking have served to protect US satellites from threats in space. Our status as the lone superpower and leader in space has meant these threats have so far been very benign. On the other hand, the future will likely hold greater threats both in number and sophistication. By taking a significant technology leap, we can defeat these future threats. This leap is broadly categorized as space stealth or cloaking. In essence, we are talking about making satellites invisible.

Most people are familiar with the stealth concepts employed on modern day aircraft such as the F-117 and the B-2. Current stealth technologies seek to blend signature reduction techniques in the radar, infrared, visual, and acoustic domains.[27] The classical design problem has been balancing aircraft designs to minimize the signature in each domain. Unfortunately, this does not lead to an optimal solution. For example, highly reflective materials are ineffective in a visual or radar environment but are very desirable in an infrared environment. In 2025, standard detection methods as well as a number of new and unique methods will have to be countered in order to achieve true stealth. The technological leap that may enable us to do this is satellite cloaking.

Satellite Cloaking

System Description. The concept of satellite cloaking takes stealth to a new level. To date, stealth has been a passive activity aimed at trying to minimize reflection and maximize absorption of energy with the goal of reducing the amount of energy reflected back to the sender. In contrast, cloaking will use active means to enable a satellite, as seen by enemy sensors, to blend into any environment.[28] Reliant on emerging material science advances as well as miniaturization and high–speed computing, a cloaked satellite will use nanotechnology robot films which will render it invisible in a space environment.

These nanotech materials, comprised of systems on the scale of individual molecules, must have two critical capabilities. First, the system must be capable of detecting any energy being aimed at the satellite. Is this possible? AT&T Bell Labs physicist Bernard Yurke sees nanotechnology systems with the sensitivity to "allow the first detection of individual photons."[29] After detection of incoming energy, the system must be capable of altering its construction to reflect or absorb that energy. With materials that have molecular motors and controllers, whole chunks of satellite skin can be made flexible and controllable. To simplify this idea of molecular manipulation, scientists describe nanotechnology through a vivid analogy. Picture an automated factory, full of conveyor belts, computers, and moving robot arms. Now imagine something like that factory but a million times smaller and working a million times faster with parts and pieces of molecular size.[30] In this concept the smart, adaptive skin of the spacecraft reacts to control inputs from the sensor array to make itself invisible to an enemy. In essence, molecular assembly lines are creating a satellite skin which is best suited to deflect or absorb incoming energy.

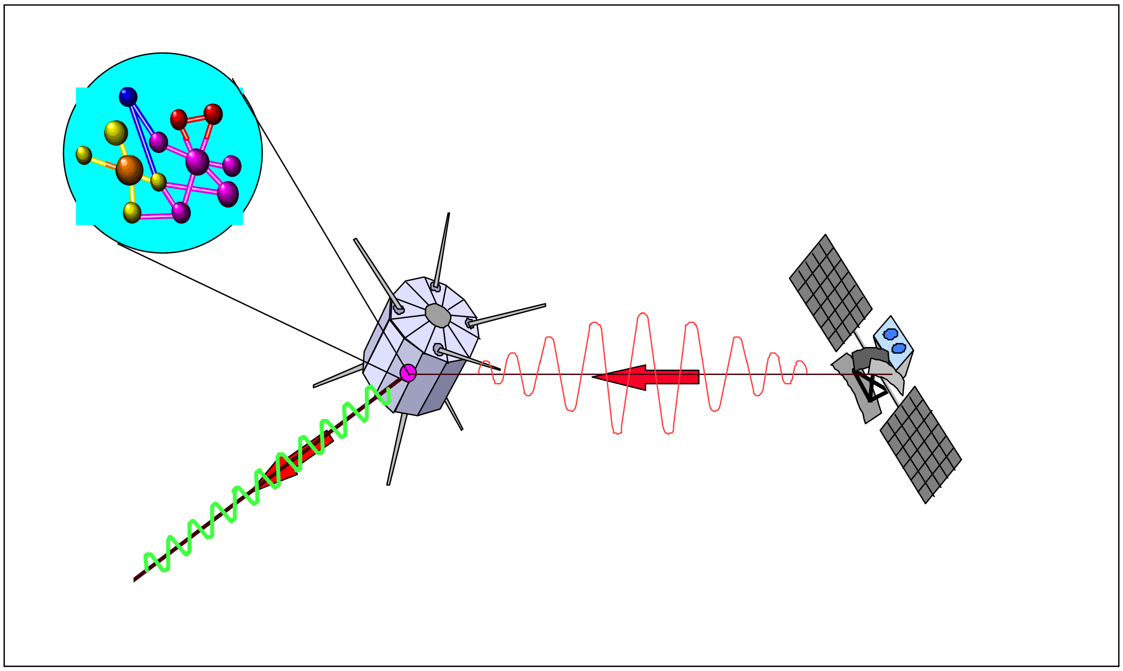

Figure 3-6. Nanotechnology Cloaking System.

Figure 3–6 depicts a friendly satellite being radiated with radar energy from a hostile source. The sensor array on the surface of the friendly spacecraft detects inbound radar energy. The control system then directs the nanotechnology satellite skin to form a radar absorbent material and take an angular shape which will reflect the radar energy away from the source. Molecular sized computers, acting as the brains of this unique defensive shield, will enable the system to react almost instantaneously to inputs from the sensor array. The advent of nanocomputers, says Drexler, will give us practical machines with a trillion times the power of today's computers, all in a molecular package.[31]

An alternate protective means is a stealthy satellite capable of generating an electrostatic or magnetic repulsion field which will shield the spacecraft from natural threats.[32] The repulsion field would be employed against low stress threats such as space debris or possibly to protect against solar flares. An important side benefit of such a repulsion field is the ability to use it as a sensor field to determine whether a satellite has been damaged by natural causes (space debris) or an attack. This capability gives the satellite controllers immediate information as to the probable cause should a satellite mysteriously drop off the screen.

Intelligent materials are another emerging technology with great possibilities in this arena. Researchers are creating materials which, inspired by nature, can anticipate failure, repair themselves, and adapt to the environment. Smart materials employ tiny actuators and motors as muscles, sensors as nerves and memory, and computational networks that represent the brain and spinal column.[33] Molecular computers coupled with molecular sized assembly lines ready to build the right shield at the right moment with materials capable of adapting to the environment may make cloaking a reality in 2025.

As far as feasibility, Stewart Brand, a leading futurist at the Massachusetts Institute of Technology, reflects on nanotechnology, stating "the science is good, the engineering is feasible, the paths of approach are many, the consequences are revolutionary-times-revolutionary, and the schedule is: in our lifetimes."[34] Commercial interest in these technology developments, for uses in adaptive assembly lines and self-repairing machines, will increase the probability they will be available for incorporation in US space systems.

Concept of Operations. The satellite cloaking system will operate on all space assets critical to US operations. This includes both military as well as key civilian spacecraft. The cloaking system will go into action once alerted by its onboard sensor array or warned by its command and control network.

First, the system will classify the incoming detection signal as radar, infrared, or visual (remember, individual photon detection is the norm). Sensor information is passed to the nanocomputer control system which relays commands to the nanobuilding blocks in the satellite skin. The building blocks, acting as their own molecular assembly lines, manufacture a skin which is optimized to reflect or absorb incoming energy. The ability to change at near instantaneous speeds allows the system to overcome the problem of suboptimal design (the trade–off between reflecting and absorbing materials) encountered in today's stealth aircraft. The nanotech spacecraft skin will be capable of battle damage repair to the spacecraft (a self-healing satellite). The ability to act autonomously to repair itself greatly reduces demand on the logistics system, which in space is a great advantage in both cost and time.

Countermeasures. The most obvious countermeasure to a nanotechnology cloaking system is the ability to disrupt the molecular interactions which enable the system to operate. The possibility also exists for a new detection spectrum, possibly a smart beam, which is capable of changing to counter a response by the cloaking system. Destruction of smart nanotechnology materials should not pose a problem as the system will be capable of rejuvenation. However, this technology can be expected to proliferate through

commercial developers to the community of space faring nations. The ability to perform the offensive counterspace mission against cloaked satellites presents its own unique challenges to US forces.

Kinetic Energy Weapons

General Discussion. Kinetic energy weapons (KEW) destroy things "the old fashioned way," that is using energy generated by a moving mass impacting a target mass. KEW for space application in the form of antisatellite (ASAT) systems date back to the mid to late 1960s when both the US and Soviet Union were testing ASAT weapons. US commitment to an ASAT changed with administrations until testing was finally terminated in 1985 and the secretary of defense canceled the F-15 ASAT Program in 1988.[35]

KEW can be employed from the ground, air, or space against targets in any medium. This paper suggests concepts which employ KEW from various platforms against ground and space targets. As noted previously, the space environment of the future will be one of multiple users of military, civil, and commercial satellites. In many cases, political considerations will prevent or severely constrain military options which involve actually destroying satellites. Having a solid KEW capability, however, will serve to deter similar aggression against US satellites and will give the US the option to destroy enemy satellites if necessary. Several concepts are proposed which take advantage of KEW technology. These include the satellite multiple attack and kill system (SMAKS) and alpha strikestar transatmospheric vehicle (TAV).

Satellite Multiple Attack and Kill System

System Description. This system is similar to the Army's multiple launcher rocket system (MLRS), but instead of ground–to–ground capability the SMAKS employs a ground to space capability.[36] The system has three models designed for attacking low, medium, and high earth orbiting satellites. Similar to the Army system it is highly mobile and carries an array of antisatellite rockets. Given the potentially large number of enemy satellites existing in 2025, enough SMAKS vehicles are needed to ensure an effective ground-based ASAT capability over the entire battlespace. The system can also be based on ships and submarines to provide the capability of destroying launch vehicles in the boost phase before they can deploy enemy satellite

systems. SMAKS carries highly sophisticated command and control, targeting, and positioning systems, requires minimum manning, and is readily deployable.

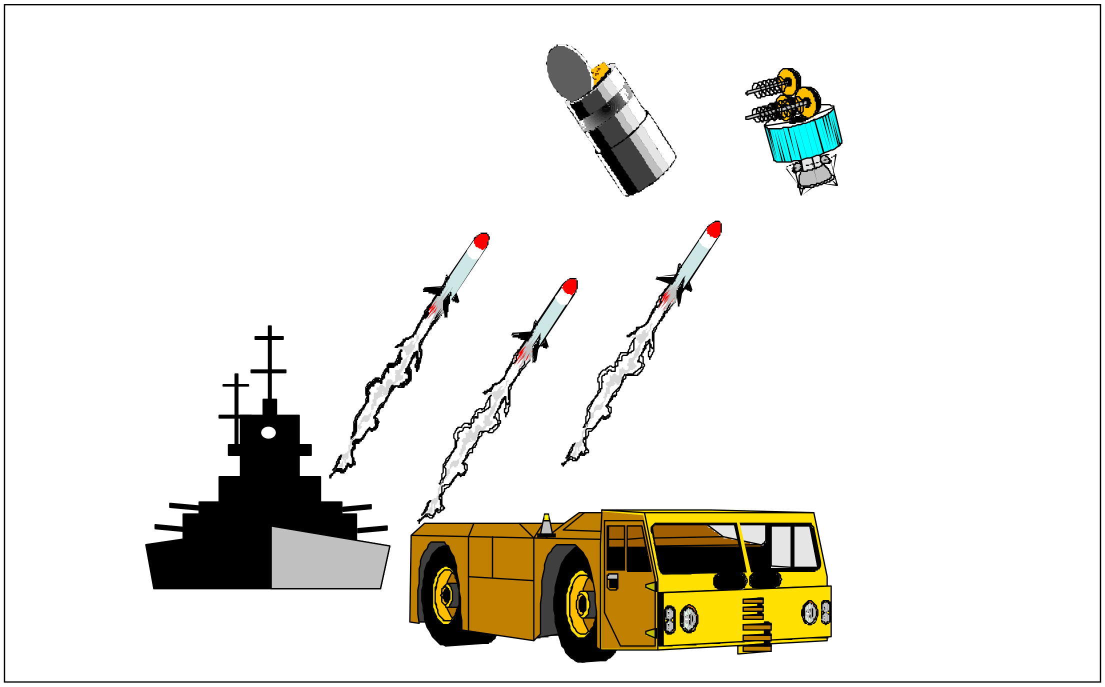

Figure 3-7. Satellite Multiple Attack and Kill System

Concept of Operations. SMAKS is sized to fit easily into the air mobility workhorse of 2025 and must be located at appropriate locations depending on the target set. The system is sea-deployable giving it added flexibility. Using the advanced global positioning system (GPS), SMAKS will take a minimal amount of time to accurately locate itself and prepare itself to conduct antisatellite operations. Upon proper direction, the SMAKS will process appropriate targeting data received from surveillance and reconnaissance assets, upload the targeting data into the appropriate number of missiles, and release the weapons. Surveillance assets will conduct battle damage assessment and feedback to the SMAKS.

Countermeasures. Potential countermeasures to this system would be electronic measures such as jamming and spoofing to confuse the required GPS information or other data links. Also while survivability is enhanced by using a mobile system, it is nevertheless vulnerable to attack from air or space while operating on the surface of the earth. Satellite maneuvering may be an effective countermeasure against a SMAKS type system that is heavily reliant on a target satellite's initial position and velocity for targeting.

Alpha Strikestar Transatmospheric Vehicle

System Description. The Alpha Strikestar is envisioned as a transatmospheric vehicle (TAV) able to take off and land horizontally and enter into low earth orbit.[37] It is able to transition between air and space environments repeatedly during the same mission, based on the threat and mission requirements. It carries multiple types of weapons to meet any threat. These include kinetic energy antisatellite missiles designed for total physical destruction and a high–powered laser cannon which is capable of disrupting, denying, degrading, or destroying unfriendly satellites. Another mission is the capture of an enemy satellite for return to earth or transfer to a useless orbit. The Alpha Strikestar is also air/space-to-ground capable using precision guided weapons to take out hard targets anywhere in the world on short notice. The vehicle is equipped with self–protective measures, as well as an imaging capability for battle damage assessment.

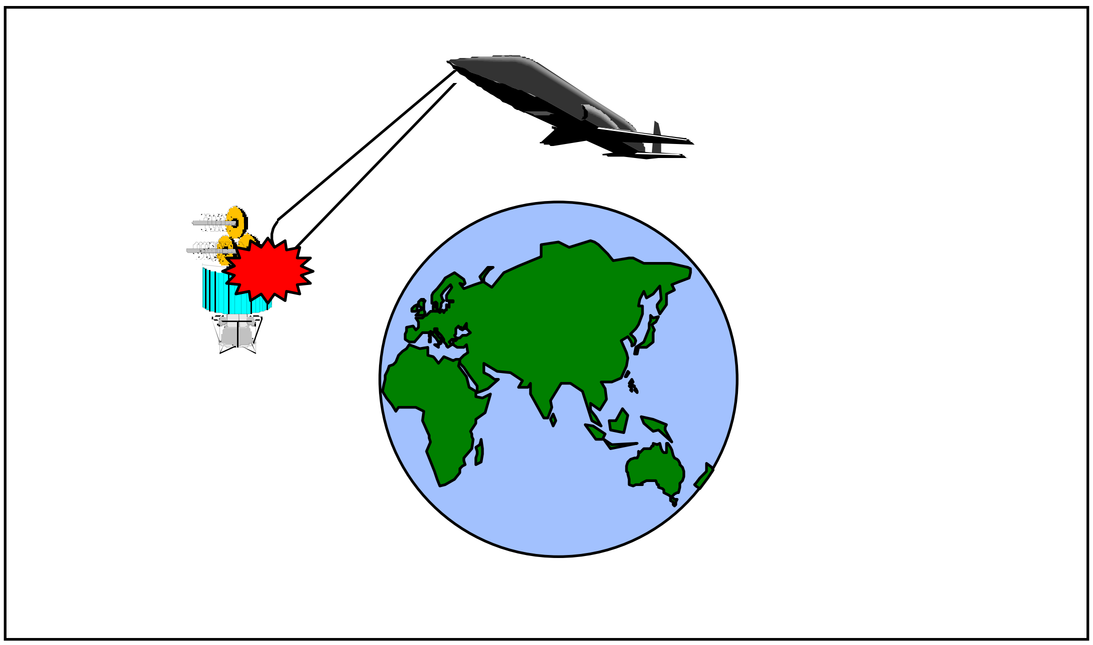

Figure 3-8. Alpha Strikestar TAV.

Concept of Operations. Alpha Strikestar can be scrambled to react to a crisis anywhere in the world on a moment's notice. Orbital insertion planning is preloaded into the weapons system computer to assist the pilot in proper positioning, target acquisition, and target engagement. For ground targets, mission planners will determine best application of weapons load (space or air delivered). The vehicle is flexible enough to enter low earth orbit en route to a ground target, reenter the atmosphere to deliver ordnance, then return to

orbit to overfly the target and conduct battle damage assessment. If necessary the Alpha Strikestar can then reengage to complete the designated mission.

Countermeasures. This system will employ state–of–the art stealth technology, but if detected will be vulnerable to enemy ASAT attack, whether it be kinetic or directed energy. Since a TAV requires ground–based launch and processing facilities as well as runways, these are likely to be targeted as critical nodes by an enemy looking to ground a TAV fleet.

Directed Energy Weapons (DEW)

General Discussion. Counterspace missions in 2025 will require the ability to disrupt, deny, degrade, and destroy enemy space capabilities. The proliferation of space users will reach monumental proportions in 2025, making counterspace attacks on individual users (the ground component) nearly impossible. The critical linkage between the user and the information he or she desires is the space–based asset and the transmitted data. Add to this situation the large future role of the space system entrepreneur and now attacking these systems may not only bring legal action against the US but may degrade our own capability. Directed Energy Weapons (DEW) of 2025 will provide the most promise for disrupting, degrading, denying, and if necessary destroying enemy space capabilities.

> A directed energy weapon must be able to generate energy, direct it on the target, propagate it through air or space, to the target, and induce some lethal effect in the target. Charged particle beams are probably the best at generating, directing, and killing but are clearly the worst at propagating. Neutral particle beams can propagate and kill but cannot yet be generated with sufficient intensities. Lasers are very good at directing and propagating, since light reflects from mirrors, can be pointed like a spotlight, and after leaving the weapon propagates in straight lines.[38]

Historically, the major drawback to DEW has been the necessity to operate in clear weather. If the DEW is placed in space to conduct space-on-space attacks, this deficiency is eliminated. If the DEW is on the ground conducting earth-to-space attacks or in space conducting space-to-earth attacks, 2025 technologies for boring access holes through clouds and other obstructions may eliminate this deficiency. Development of a high–powered microwave weapon which can operate in all weather conditions may eliminate the poor weather deficiency. The current airborne laser (ABL), being developed to counter theater ballistic missiles, will demonstrate the ability of lasers to operate in environmental turbulence of the earth’s atmosphere. The

recently completed *New World Vistas Directed Energy Volume* report by the Air Force Scientific Advisory Board indicates, "the ABL will probably be the first practical and effective directed energy weapon to be deployed."[39] This will be the springboard to operating lasers through the medium of air and space. By 2025, DEW systems will likely operate in space and from the ground. This will give us the ability to negate objects in the atmosphere and in space. Five directed energy concepts were explored in this study.

High Energy Laser Attack Station (HELAS)

System Description. Disrupting, denying, degrading, and destroying enemy space capability will be accomplished by a space–based high–powered, short wavelength, solid state laser platform. This constellation of orbiting platforms will provide continuous, 24-hour protection of friendly forces and negation of enemy capabilities.[40] This constellation of counterspace platforms will be placed in low earth orbit (LEO—150 NM), medium earth orbit (MEO —11,000 NM) and geosynchronous orbit (GEO—22,000 NM). The high energy laser attack station (HELAS) will consist of 16 orbiting platforms at LEO, eight platforms at MEO, and four platforms at GEO. This multilevel constellation will provide a layered interactive defense against all space-borne or space-transiting threats. The multilevel system will protect all US assets in various altitudes and inclinations. A diode pumped solid state laser (DPSSL) will be the heart of the laser weapon subsystem. The DPSSL is more efficient than flashlamp pumping, which is the traditional method of exciting solid state lasers, and it results in much less heating of the laser as well.[41] Current solid state, chemical, and free electron lasers can generate power in the kilowatts range. However, a credible HELAS must employ lasers in the megawatt ranges. There appears to be no major technological limitation for DPSSL to achieve the megawatt range, and continued advancements will reduce the cost to reasonable limits.[42]

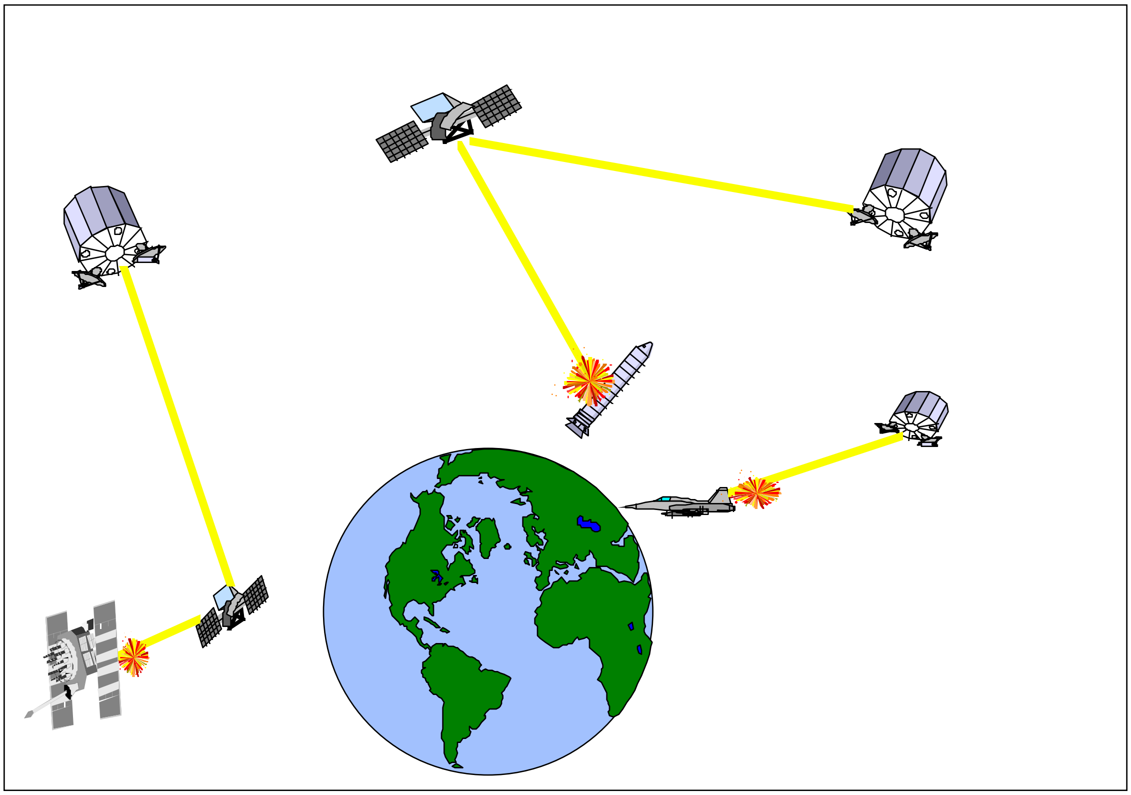

Figure 3-9. HELAS.

Concept of Operations. The HELAS will be the primary space attack/defense network for counterspace operations in 2025. The multilayer, multiinclination constellation will be operated by a single ground crew member (ops chief) with the assistance of artificial intelligence health and maintenance software systems.[43] Ground– based telemetry, tracking, and controlling will be conducted via satellite-to-satellite laser crosslinking. Another crew member will serve as the weapons manager who will track, target, and engage hostile targets. These two crew members can sit side by side in any size facility and in any location on the globe as long as they can communicate with at least one satellite. The crosslinking capabilities will provide the global command and control necessary to operate the constellation. Enemy ground launched or co-orbital ASAT can be detected, tracked, and engaged by HELAS. Although primarily a denial/destruction type weapon, the laser can be tuned to damage or degrade satellites by attacking subcomponents (i.e., solar array panels, reaction control thrusters, thermal heating of components to cause system shutdowns, etc.). Counterspace earth targets such as command and control (C^2) facilities, earth station antennas, spacelift facilities, and spacelift vehicles can also be effectively engaged by HELAS. The four GEO platforms could

also provide dual–use capabilities for planetary defense by orienting HELAS outward. This could be done in a global emergency noting the degradation of the space defense mission with the GEO platform oriented outward.

Countermeasures Special reflective or absorbent material could make the laser ineffective. Use of low-observable or stealth technology may defeat targeting and identification systems on the HELAS. The HELAS may be vulnerable to anti-satellite weapons or other laser stations. In addition, satellite hardening may be an effective countermeasure against low power laser pulses intended to degrade the target. This may force commanders to opt for the hard kill destruction of hardened satellites. A factor driving this decision will be the potential political impact of a turn in negative international opinion resulting from the total destruction of a satellite.

Solar Energy Optical Weapon (SEOW)

System Description The SEOW will use the evolutionary concept of large orbiting structures to focus solar rays on earth and space targets to disrupt, deny, degrade, and destroy enemy capabilities.[44] This concept constructs a 10 kilometer magnifying glass or focusing element in space to illuminate targets on the ground or in space. This illumination can turn night to day on the ground, scorch facilities, or overheat satellite components. The solar energy provided to the focusing element on the weapon also provides a perpetual power source for the orbiting platform. Instead of using an orbiting magnifying glass to focus energy, another alternative is to use stored solar energy to power a directed energy weapon. A leap in battery technology leading to the capability to store immense quantities of power can be expected by 2025.

Large lightweight structures (kilometers) are feasible for 2025 and will provide the necessary stable platform to house the focusing or magnifying glass element. Advancements in space membrane structures and adaptive optics may provide the necessary capabilities to produce an energy frugal space–based weapon. Each SEOW will orbit at geosynchronous altitude and consist of an Attitude Control System, Guidance, Navigation, and Control System, Reaction Control System, Targeting and Identification System, and the Laser Communications System.

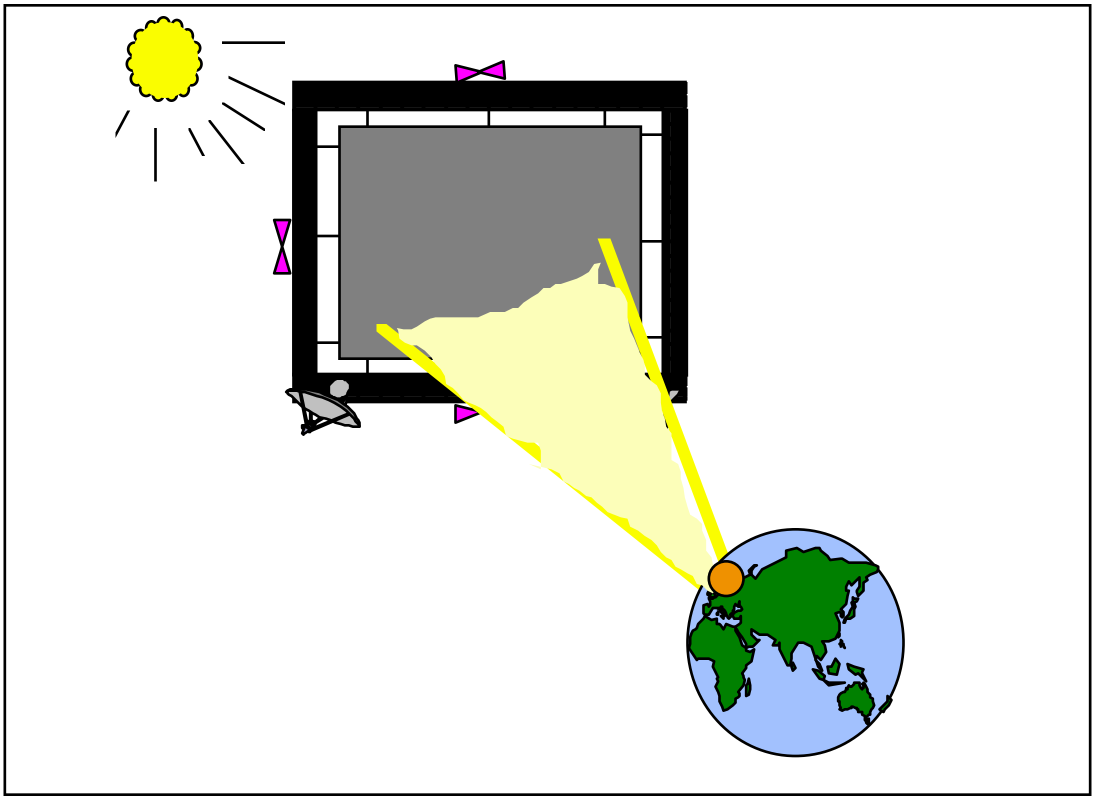

Figure 3-10. Solar Energy Optical Weapon.

Concept of Operations. The orbiting SOEW will be assembled in low earth orbit and boosted into geosynchronous orbit after the completion of the 10-kilometer optical focus assembly. The weapon can be maneuvered over the area of interest to provide space-to-earth capabilities as well. The solar energy can be spotted over a particular area of interest turning night into day. In addition, the beam could be focused on a power generation facility on the ground to provide a continuous high– energy source or the station could focus its beam on a lower orbiting satellite to provide it solar power when it would normally be in the earth's shadow. The beam could also be focused on an enemy orbiting threat to raise the internal temperature beyond functional limits. This may not destroy the satellite but, because of low sensitivity to heat, will force the automated shutdown of the satellite. Enemy controllers will only be able to detect the out–of–limit condition but will be unable to detect the source. For imaging and electronic surveillance satellites which pose a great threat to our forces (i.e., removes element of surprise), the SEOW will illuminate the target prior to its entry into the area of responsibility forcing an automated shutdown of the satellite or blinding of its sensors, thus preventing collection over our assets. Once the target has departed the protected area,

illumination is discontinued until the next threat enters the area. Although this will completely deny use of the imaging/reconnaissance platform to all users for that period of time, US surveillance capabilities will be provided by other US government–controlled assets.

Countermeasures. As a large fragile target, the optic or space membrane could be easily disrupted or destroyed by KEWs or objects. Enemy forces could attempt to ram the weapon with a kamikaze satellite in hopes of rupturing the adaptive optic system. As a result, an active defense system will be needed to counter this potential threat. An alternative is to use a large number of small membranes coupled with adaptive optics to form a synthetic aperture type focusing element. This will make the array less vulnerable by dispersing the elements which makeup the optics system.

Electromagnetic Pulse (EMP) and High Power Microwave (HPM) Pills

System Description.[45] EMP radiation can be viewed as variations or created disturbances in the electromagnetic field which can cause disruption of electronic devices by arcing, overloading, and discharging. These EMP charges can be generated by numerous sources and can cause limited to extensive damage to electronic components. High power microwaves (HPM) can penetrate external protective surfaces and disable or damage critical components of a satellite or other spacecraft. The HPM weapon might be focused on specific circuits and subcomponents within the target in order to disrupt or degrade mission functions.[46] Focusing and tuning the HPM to a specific wavelength or frequency might allow certain components to be isolated and affected. The EMP or HPM pills will be microsatellites which maneuver within close proximity of an enemy satellite and emit short–range pulses to interfere with the normal operation of the satellite.[47] These pills are intended for short duration operations in order to minimize the potential for collision with friendly satellites. These microsatellites will be launched into space by aircraft, transatmospheric vehicles (TAVs), small launch vehicles, or small fighter aircraft using high impulse air-to-space missiles. After 30 to 60 days, the pills will be directed to move to a collection orbit to be recaptured by TAV. The EMP/HPM pill will consist of small, lightweight satellites with an EMP gun or HPM generator attached. This compact, short–range weapon will provide an adequate offensive counterspace capability which will be undetected by the enemy. Because of the longer wavelengths and wider beams generated by

EMP type weapons, pointing accuracy will not be as critical as those needed for laser type weapons. Although some EMP/HPM weapons exist today, the challenge for 2025 require miniaturization of the spacecraft and the applicable weapon.

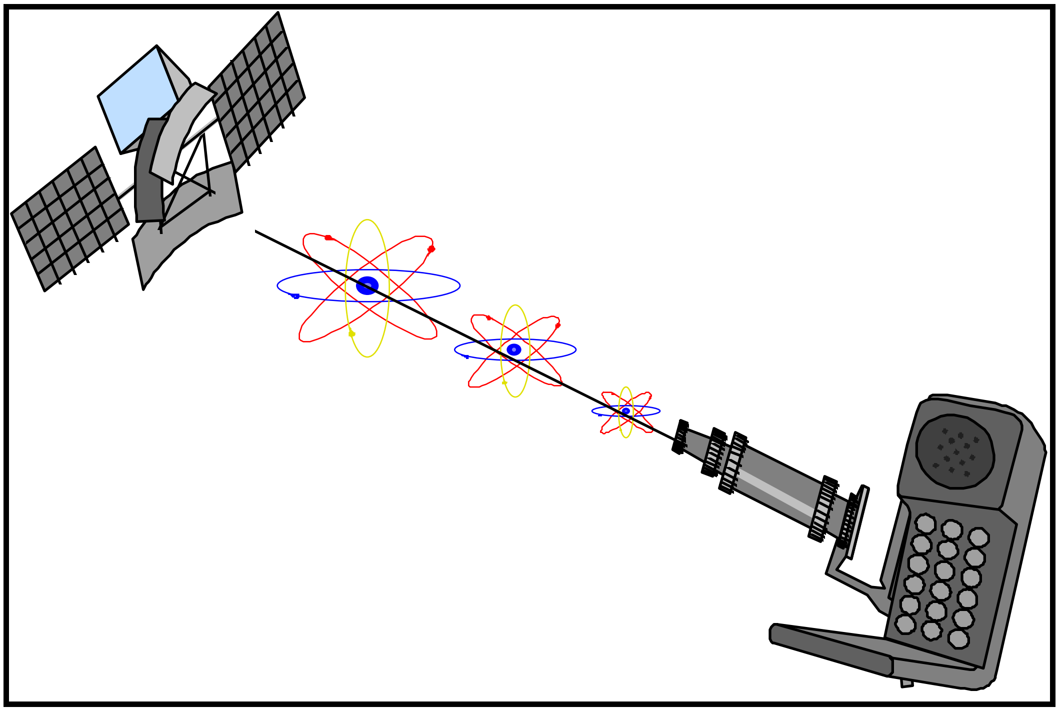

Figure 3-11. EMP/HPM Pill.

Concept of Operations. During prehostilities and during crises/war, EMP/HPM pills will be launched into orbit. These microsatellites will be positioned next to high– value enemy satellite systems and space systems operated by neutral countries or multinational corporations which may supply information to the enemy. The EMP/HPM pills will fly in formation with the enemy satellites until directed to engage. The explosive generator (or applicable weapon) will fire a fine tuned graduated pulse at the target. The goal is to deny the space capability through disruption and not destruction. This is especially true in the case of multinational corporation satellite systems. The pill can fire several rounds over a 60–day period at key times during the enemy satellite's orbit when it is collecting information on US forces or downlinking data to the ground. When the EMP/HPM pill has completed its mission or is no longer necessary, it can be deorbited and allowed to decay in the earth's atmosphere. The EMP/HPM pills can provide local neutralization of enemy satellite systems over the battlefield as well as global with a large number of cheap weapons.

Countermeasures. System shielding and electrical ground may reduce the effectiveness of the EMP/HPM pill. If detected, the enemy could maneuver out of harms way or fire a kinetic or directed energy weapon to degrade or destroy the EMP/HPM pill. Dispersion (spreading the mission over a larger number of smaller satellites) is another countermeasure. The resulting increase in numbers will force a corresponding increase in the number of EMP/HPM pills and will make degradation of the system more difficult. Our forces could counter by making EMP/HPM pills cheaper and easier to operate than the target satellite system.

Ground–Based Laser (GBL)

System Description. The GBL provides the capability to disrupt, deny, degrade, or destroy enemy space capabilities and potentially protect friendly space assets.[48] Several ground–based laser concepts have been explored over the past 25 years. Ground– based lasers offer unique advantages over space–based laser systems. Supportability and operability are major advantages to the ground–based laser. Deployment and supportability is functionally easier on a ground–based system than on an orbiting space system. There are two major drawbacks to ground–laser systems: line–of–sight limitations and atmospheric perturbation.

This concept will develop the laser station on the earth, fire the laser at relay optics in space, and use those relay mirrors to engage targets either in space or on the earth. This places the most technically challenging component on the ground and deploys a very simple relay network system in orbit. Three to five laser generation sites will be placed in various locations across the continental United States (CONUS). These sites will have access to relay mirrors orbiting above, which can transfer the laser beam to other orbiting relay stations to attack targets on the other side of the globe. Dispersion of the laser stations and relay mirrors will help defeat the poor weather deficiency which has plagued the capability of ground lasers to fire through cloud cover into space. The Laser Guidestar program developed technology for atmospheric compensation which allows a ground telescope site to view a scene or irradiate a target anywhere around the globe while a relay mirror is in position to provide the view.[49] This technology will greatly contribute to our future ability to bounce lasers off orbiting mirrors to attack targets.

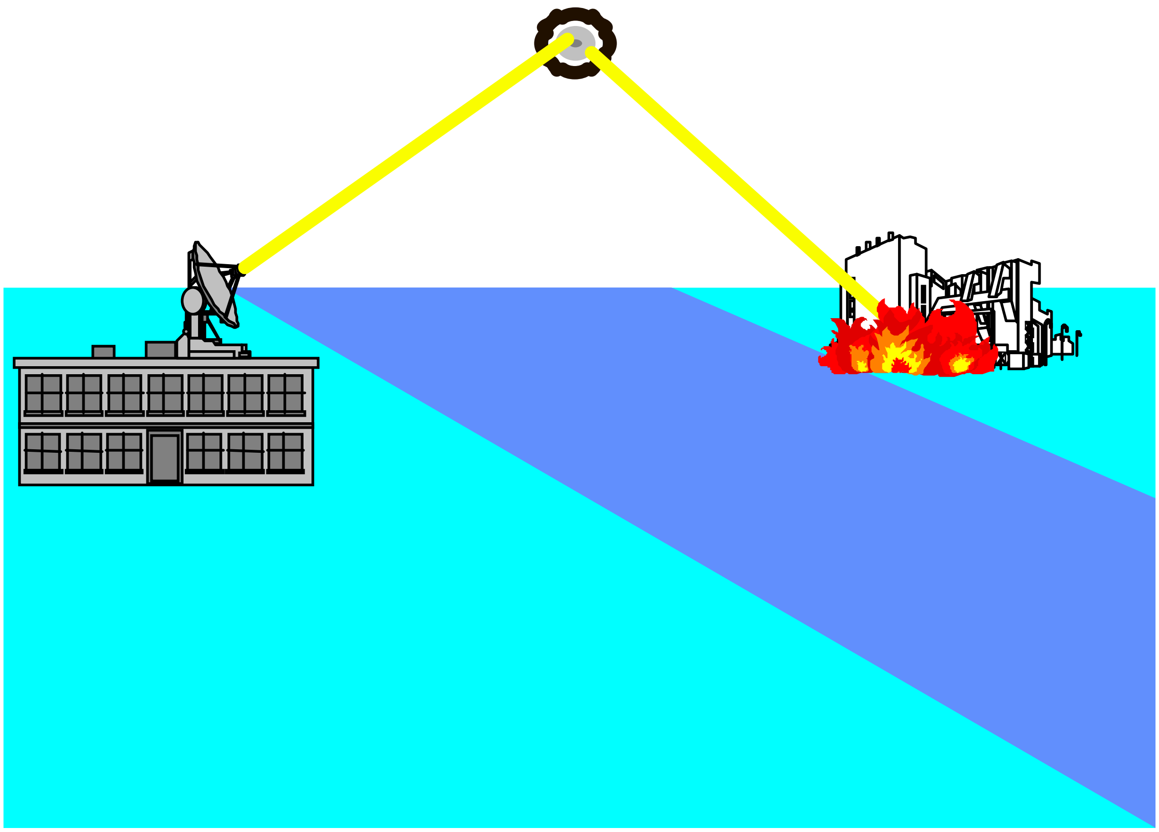

Figure 3-12. Ground–Based Lasers.

Concept of Operations. The five laser generation stations will be placed in those geographical locations best suited for laser operations and favorable weather conditions. Wide dispersion of these sites will increase the probability of having at least one site in clear weather for optimum operation. The laser generation site will be an unattended nuclear–powered facility which will provide the necessary megawattage required for the high–powered solid–state laser. Control of the five stations and the orbiting mirrors will be centralized in a primary facility with a mobile backup facility. Redundant satellite communications between the laser generation sites will increase survivability of the ground–based laser system. The orbiting mirrors will be laser crosslinked to reduce the ground support network for telemetry, tracking, and control (TT&C). The same reflecting mechanism used to attack a target can be used to identify and track the object before engagement. This information will be processed by ground computers at the central control facility and attack commands will be issued to the laser ground sites. Recycle times can be

reduced to instantaneous rapid fire by using multiple laser generating sites to engage multiple targets. Different relay paths can be used to add redundancy to the system and also mitigate the problem of limited number of discharges by a single laser site.

Countermeasures. Ground–based laser generation facilities are susceptible to conventional attack or sabotage. The orbiting mirrors will be susceptible to ASAT attack however, a large constellation of cheap orbiting mirrors is a natural counter to these measures. Excessively poor weather conditions across the entire CONUS will degrade the network capability. This may require overseas or outside the continental United States (OCONUS) basing (i.e., Hawaii, Alaska, Guam, Puerto Rico, etc.). The ability to actively modify weather conditions could be used to defeat a ground–based laser system by planting clouds over the laser site. On the other hand, the ability to remove cloud cover through weather modification may be an effective counter to the effect of poor weather on ground–based lasers.

NOTES

[1] US Naval War College (USNWC), *Technology Initiatives Game (TIG) 95* (Newport, RI, 1995), 5-1.

[2]. Ibid., 147-1.

[3.] Ibid., 54.

[4] Air University, *Air & Space in 2025 Research Study 2025*, Maxwell AFB, Ala., undated Counterspace team concept unnumbered. The space interdiction net is a possible technical approach to the problem of total battlespace awareness. Scientists argue that this may not be practical or possible by 2025. Taking this into account, this concept was rated low (i.e., beyond 2025) in the technology challenge area of the systems analysis.

[5] John L. Peterson, *The Road to 2015* (Corte Madera Calif.: Waite Group Press, 1994), 203.

[6] Air University, *Air & Space in 2025 Research Study 2025*, Maxwell AFB, Ala., draft, excerpt from "Weather Modification, Force Multiplier in 2025."

[7] William Genoa, "Smallsats Come of Age," *Ad Astra*, November-December 1994, 2210.

[8] Kaigham J. Gabriel, "Engineering Microscopic Machines," *Scientific American*, September 1995, 150.

[9] USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century* (unpublished draft, the space technology volume, 15 December 1995), 49.

[10] Robert Langreth, "Molecular Marvels," *Popular Science*, May 1993, 91.

[11] *New World Vistas*, (unpublished draft, the materials volume), 125.

[12] ***2025*** Concept, no. 900432, "Mantle Communications System," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[13.] K. Eric Drexler and Chris Peterson with Gayle Pergamit, *Unbounding the Future, The Nanotechnology Revolution* (New York,: William Morrow and Company, Inc., 1991), 203.

[14] Richard Szafranski and Martin C. Libicki, *". . .Or Go Down In Flame"? Toward An Airpower Manifesto for the 21st Century*, 4. Further information from Dr Libicki , INSS, Lecture to Air Command and Staff College, 25 March 1996.

[15] Charles Babcock, "The Incredible Shrinking Computer," *Computerworld*, October 1993, 6.

[16] Air University, *Spacecast 2020-Volume II* (Maxwell AFB, Ala.; Air University Press, June 1994), M10-M13.

[17] Air University, *Spacecast 2020-Operational Analysis*, (Maxwell AFB, Ala.; Air University Press, June 1994), 59–60.

[18] ***2025*** Concept, no. 200049, "Satellite Reactive Armor (C007U)," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[19] ***2025*** Concept, no. 200170, "Electronic signals duplication," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[20] ***2025*** Concept, no. 900336, "Cloaking," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996); ***2025*** Concept, no. 900338, "Stealth Technology," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996); ***2025*** Concept, no. 900378, "Smart metals aircraft," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996) and ***2025*** Concept, no. 900605, "Active Cloaking Film/`Paint`," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[21] Sun Tzu, *The Art of War* (Oxford: Oxford University Press, 1963), 66.

[22] *Electronic Warfare Threat to US Communications* (U), Defense Intelligence Agency. (Secret) Information extracted is unclassified.

[23] Ibid., 32.

[24] Maj James G. Lee, Counterspace Operations for Information Dominance (Maxwell AFB, Ala.: Air University Press, 1995), 34.

[25] Charles A. Fowler and Robert F. Nesbit, "Tactical Deception in Air-Land Warfare," (derived from Defense Science Board Study 1982–83), 17.

[26] J. Jones, *Stealth Technology—The Art of Black Magic* (Blue Ridge Summit, Pa.: Tab Books, 1989), 2.

[27] Ibid., 13.

[28] ***2025*** Concept, no. 900336, "Cloaking," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996); ***2025*** Concept, no. 900338, "Stealth Technology," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996); ***2025*** Concept, no. 900378, "Smart metals aircraft," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996) and ***2025*** Concept, no. 900605, "Active Cloaking Film/`Paint`," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996). Nanotechnology offers a very great return on investment if it can be applied to technologies such as cloaking or molecular–sized computers. This paper explores a possible technical approach to space stealth which some scientists argue will not be practical or possible by 2025. This concern is addressed in the systems analysis by assigning such systems a low score (i.e., probably beyond 2025) in the technology challenge category.

[29] John Travis, "Building Bridges to the Nanoworld," *Science*, March 1994, 1703.

[30] K. Eric Drexler and Chris Peterson with Gayle Pergamit, *Unbounding the Future, The Nanotechnology Revolution* (New York, William Morrow and Company, Inc., 1991), 20.

[31] Ibid., 144–145.

[32] ***2025*** Concept, no. 901178, "Space Debris Repulsion Field," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[33] Craig A. Rogers, "Intelligent Materials," *Scientific American,* September 1995, 154.

[34] Ibid., 5.

[35] Roger C. Hunter, *A United States Antisatellite Policy for a Multipolar World,* (Maxwell AFB, Ala.: Air University Press, October 1995), 17–24.

[36] Air University, *Air & Space in 2025 Research Study 2025*, Maxwell AFB, Ala., undated, Counterspace team concept unnumbered.

[37] ***2025*** Concept, no. 900292, "Alpha Strikestar Transatmospheric," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[38] Maj Steve R. Petersen, USAF, *Space Control and the Role of Antisatellite Weapons* (Maxwell AFB, Ala.: Air University Press, 1991), x.

[39] *New World Vistas*, (unpublished draft, the directed energy volume), vi.

[40] ***2025*** Concept, no. 900420, "Laser Attack Station," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[41] *New World Vistas*, (unpublished draft, the directed energy volume), x.

[42] Ibid., vii.

[43] Some scientists have argued the level of artificial intelligence required will not be achieved by 2025. This study acknowledges this debate, however, HELAS will gain most of its advantage from the ability to

crosslink data and command throughout the entire constellation. This ability has just been demonstrated with the current Milstar constellation. The ability to use artificial intelligence for routine satellite "state of health" will be the next milestone, preceded by the ability to handle all TT&C responsibilities.

[44] ***2025*** Concept, no. 900163, "Solar Energy Weapon," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[45] ***2025*** Concept, no. 900270, "EMP Pills," ***2025*** concepts database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

[46] E. E. Cassagrande, *Non-lethal Weapons: Implications for the RAAF* (Fairbain, Australia: Air Power Studies Centre, 1995), 4.

[47] The EMP/HPM pill is a possible technical approach to solving the problem of clandestine attack on a space adversary's system. An energy source sufficient to fire EMP or HPM bursts as well as a propulsion system to maneuver the pill into position are technology areas which must be addressed. Some scientists have argued that these technology advances will not be practical or possible by 2025.

[48] *New World Vistas,* (unpublished draft, the directed energy volume), vi.

[49] Ibid., vi.

Chapter 4

Concept of Operations For a Counterspace Architecture

To assure US space superiority over the global battlespace, all elements of the enemy's space infrastructure and system of systems must be put at risk. Counterspace operations can be offensive or defensive and future commanders will require a variety of counterspace tools to engage various threat scenarios. Offensive counterspace operations seek to neutralize enemy space capabilities before they can be employed against friendly forces. Offensive counterspace missions will target enemy space capabilities on the ground (such as ground control stations or space launch complexes), assets already in space, and satellite communication links.[1] To protect our vast array of high leveraged satellite systems, defensive counterspace will neutralize hostile threats. Defensive counterspace systems will protect both military and civilian space assets and deny any enemy the ability to degrade the effectiveness of US space systems. Both offensive and defensive space missions are required to fully achieve space superiority.

Offensive Counterspace Operations

Within our offensive counterspace architecture, several previously discussed concepts will provide the means to deny, degrade, disrupt, and, if necessary, destroy enemy space capabilities. To identify and monitor space up and down link communications, the Space Interdiction Net concept will provide instantaneous monitoring and accurate identification of any space communication to or from the ground via space-based systems. Unique links may be targeted for denial, disruption, degradation, or destruction while preserving friendly signal integrity. The Space Interdiction Net provides commanders complete space situational awareness as well as a number of discreet options to target enemy links. This is very important considering

multinational use of identical space systems when only one nation may be the offensive counterspace target. The Space Interdiction Net concept provides this valuable service, with or without knowledge of the space system's owning country or corporation. Blended with space targeting and detecting systems (laser designators, Anti-ASAT subsystems, and gravity gradiometers), offensive space systems will target the entire spectrum of enemy space capabilities. Soft kill systems such as robo-bugs and EMP/HPM pills will selectively jam or interrupt a satellite's signals without destroying it. Jamming the data transmission from the sensor to the ground user will not be sufficient in 2025. Once the sensor has collected the data (in the case of surveillance and reconnaissance), the data can be dumped to suitcase size receivers any where on the globe. Instead of targeting the data stream, it may be necessary to halt the collect of the information. EMP/HPM pills, robo bugs, and other soft-kill or temporary blinding weapons will prevent collection over the area or interest which stops the mission at the input stage. This capability greatly increases flexible response options available to space battlefield commanders.

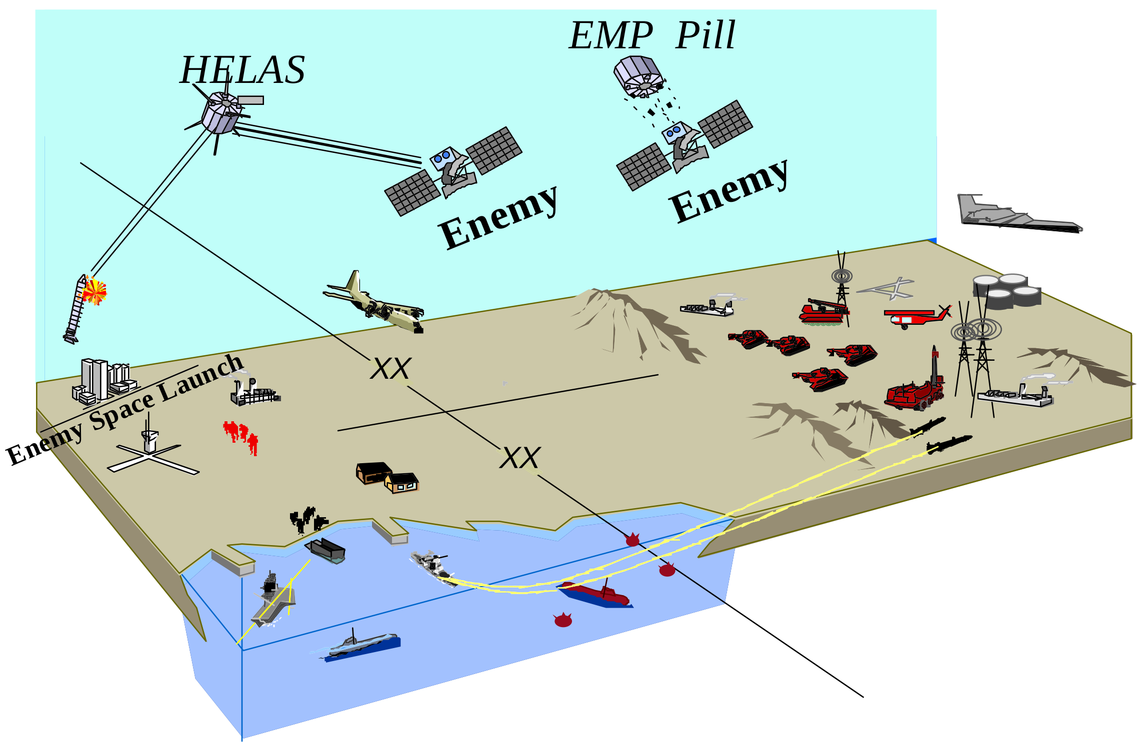

Figure 4-1. Offensive Counterspace architecture.

At the more resolved end of the counterspace spectrum lies physical destruction of enemy space capabilities. Force–on–force engagements may be necessary to destroy enemy capabilities or resupply

efforts. Directed energy weapons (ground– or space–based lasers, Strikestar TAV) provide commanders instantaneous destruction options for global and theater control. Kinetic energy weapon systems (surface, air, or space based), because of range and time limitation may best provide kill capabilities in the area of responsibility however, they can also engage globally from prepositioned locations. With a variety of offensive counterspace weapons to provide flexible engagements options to decision makers, we must also possess responsive and capable defensive counterspace systems.

Defensive Counterspace Operations

Defensive counterspace operations consist of active and passive measures designed to reduce the effectiveness of enemy space systems targeted against friendly interests. Active defense measures detect, identify, intercept, and disrupt or destroy threatening space systems. Passive defense involves protecting friendly space assets by satellite design and maneuver, warning commanders of enemy space threats, and minimizing these threats though camouflage, emission control, deception, and decoys, thus denying the enemy space data.[2] The Space Interdiction Net provides a valuable defensive capability by monitoring, and if necessary, targeting enemy communication links. In addition, capabilities such as cloaking and satellite bodyguards will be integrated to protect friendly space assets. Successfully employing coordinated offensive and defensive counterspace operations leads to space superiority. The High Energy Laser Attack Station (HELAS) and Ground Based Laser (GBL) offer immediate defensive kill capability. These flexible defensive systems can provide near instantaneous response to detected and identified threats to our space system.

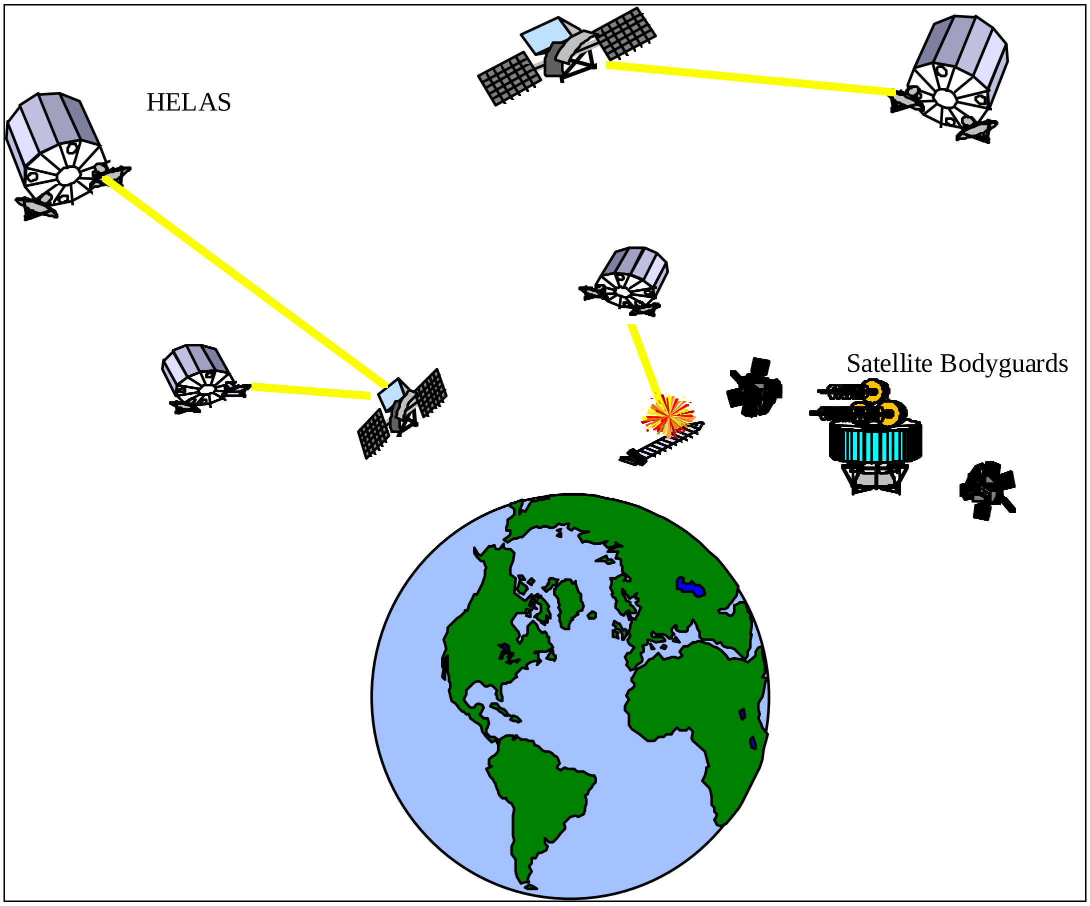

Figure 4-2. Defensive Counterspace Operations.

As more and more nations expand commercially and militarily into space, space superiority will make the difference between victory and defeat in future wars. Many nations learned a great deal from the Persian Gulf War. They noted not only the significance of precision-guided munitions but also the importance of space-based force enhancement.[3] Space is the ultimate high ground—a center of gravity in any future conflict. Whoever commands that high ground in all forms will dominate future warfare.

NOTES

[1] *Air Force Doctrine Document 4, Space Operations Doctrine (First Draft*), 15 August 1995, 12–13.
[2] Ibid., 13.
[3] Lt Col Michael R. Mantz, *The New Sword: A Theory of Space Combat Power* (Maxwell AFB, Ala.: Air University Press, 1995), 6.

Chapter 5

Investigation Recommendations

Space has been called the final frontier, the ultimate high ground, and the wave of the future. Space systems have long been recognized for their contributions to the national security of the US and have proven themselves invaluable in the conduct of modern warfare. As we approach the battlefield of 2025, we must recognize that because space is so totally integrated into the fight, we have no choice but to protect friendly space assets through defensive and offensive counterspace operations as necessary to prevent an adversary from exploiting space systems against the US. Today, we stand on the threshold of an era which will see massive integration of space systems into the way of life of the nations of the world. Those that most effectively leverage space systems will be the political, economic, and military leaders of the world of 2025.

In order to make sure the US stays out in front in space power, we must begin planning now for the counterspace architecture of 2025. Key to this effort is to be proactive in developing the technologies, systems, and operational concepts for counterspace, rather than waiting until an adversary threatens, or worse, destroys one or more US space assets. This paper has discussed key technology areas required to implement certain promising concepts to achieve space superiority. These technologies are detection and targeting, miniaturization, stealth, kinetic energy weapons, and directed energy weapons.

Detection and targeting is a key technology area which is critical to the effective employment of counterspace weapons. Dominant battlespace awareness is critical in achieving space superiority. This area is especially challenging in the 2025 space environment where satellites are used by commercial and military users alike and we must have the capability to identify and target only the appropriate parts of a mission payload or its signal. Next, miniaturization must be pursued to reduce the critical aspects of size, weight, and

cost when lifting large numbers of satellites into orbit. Work going on now in the areas of microelectromechanical systems, micro- and nanotechnology must continue and be tested in order to determine space applications. Given the likely threat capabilities of potential adversaries in 2025, the next technology, stealth, is especially critical to passively and inexpensively protecting US satellites from attack. This type of stealth is the application of nanotechnology and molecular manipulation to make satellites invisible to sensors. There is significant research, development, and testing going on in this area, and it must continue. A fourth area, kinetic energy weapons, will provide the needed capability to hold enemy satellites at risk of total destruction. This capability has already been proven from the air. Technology advances are needed to make this a capability from the ground in large numbers. Finally, the most promising means of force application lie in the area of directed energy weapons. Today the airborne laser is well on its way to operational status. This system must continue to be supported so that it can prove the feasibility of laser weapons. The follow–on efforts to airborne laser will need to prove directed energy weapons can be operated from air to space and within space. An analysis aimed at prioritizing these concepts with recommendations for future development follows.

Future Concepts—A System Analysis

In order to determine which of the counterspace concepts presented in this paper are most likely to yield the maximum return on investment, we have attempted to rank them using a subjective system analysis. Each system is scored in a number of categories which represent those characteristics most likely to contribute to air and space superiority in 2025. In addition, the systems have been scored in areas representing cost, schedule, and technical feasibility (table 3). The categories used to score the systems are:

Commercial Applicability - The extent to which the concept has technology spin-offs which contribute to the commercial sector. (5= very high commercial application; 1= very low commercial application).

Availability - Probability that the system will be operational in 2025. (5= very probable; 1= very improbable).

Payback - Return on investment will be very critical, especially in a world in which the defense budget is shrinking. (5= very high return on investment; 1= very low return on investment).

Contribution to Air and Space Superiority - Probability that a particular system will spur a military technical revolution in 2025 (a silver bullet system). (5= revolutionary contribution to air and space superiority; 1= minimal contribution).

Cost - An order of magnitude estimate of system cost. (5= system cost measured in millions; 3= system cost measured in billions; 1= system cost measured in trillions).

Lethality - Probability of kill (for offensive systems) or probability to prevent hard kill (for defensive systems). (5=very high probability of kill/save; 1=very low probability of kill/save).

Selectivity - Represents the range of options a system offers in terms of offensive or defensive capabilities. For offensive systems, selectivity measures the ability to inflict hard kill, soft kill, or both. For defensive systems, selectivity represents the ability to protect against hard kill, soft kill, or both. (5= offers all options [hard kill, soft kill, both]; 1= offers no options).

Technology Challenge - The probability that technology will advance enough in key areas to provide the capability described in the concept. (5=forecast by 2025; 4=plausible by 2025; 3= possible by 2025; 2= beyond 2025; 1= well beyond 2025).

Table 3

System Analysis Score Sheet:

Miniaturization, Stealth, and Detection/Targeting Concepts

	Satellite Bodyguards	Robo-bugs	Satellite Cloaking	SMAKS	Gravity Gradiometer	Anti-ASAT	Space Interdiction Net
Commercial Applicability	2	2	4	2	2	1	4
Availability	4	4	2	4	3	3	3
Payback	4	5	3	3	3	2	5
Contribution to Air/Space Superiority	4	5	3	3	2	3	5
Cost	3	4	2	3	3	3	2
Lethality	5	4	4	3	3	3	5
Selectivity	4	5	3	2	3	3	5
Tech Challenge	4	3	2	5	2	4	3
Total	**30**	**32**	23	25	21	22	**32**

Table 4

System Analysis Score Sheet:

Kinetic Energy and Directed Energy Concepts

	Alpha Strikestar TAV	High Energy Laser Attack Station	Solar Energy Optical Weapon	EMP/HPM Pills	Ground Based Laser
Commercial Applicability	4	2	4	4	2
Availability	4	3	2	4	4
Payback	5	4	4	3	4
Contribution to Air/Space Superiority	5	5	4	4	4
Cost	2	1	2	5	3
Lethality	4	5	4	4	5
Selectivity	4	3	4	4	3
Tech Challenge	4	4	3	3	5
Total	**32**	27	27	**31**	**30**

Based on this subjective analysis of the counterspace systems developed in this paper, a natural break in the scores appears. Those systems which fall “above the line (score of 30 or better), would seem to offer the greatest potential to contribute significantly to control of the air and space environment in 2025. Those systems (in priority order according to table 3 and table 4) are

1. Space Interdiction Net (32)
2. Alpha Strikestar TAV (32)
3. Robo-bugs (32)
4. EMP/HPM Pills (31)
5. Ground Based Laser (30)
6. Satellite Bodyguards (30)

In ranking the concepts at the top of the list, a number of factors were considered. Developing the Space Interdiction Net by 2025 pushes the technology development envelope to its maximum. However, the return is a silver bullet system which could significantly impact the way any future war in space is waged. On the other hand, the Alpha Strikestar TAV and robo-bugs offer exceptional capabilities but do not make the revolutionary impact on how war is waged that the Space Interdiction Net offers (table 4).

Each of the systems presented will rely heavily on breakthroughs in miniaturization and high–speed computing, both technologies which should see significant commercial development in the future. It is critical that the military capitalize on these advances in technology to develop systems that will offer uncontested access and control of space. Investment in systems such as those presented here will provide this capability in the future. The challenge is to move from the present to the future—where Star TEK is used to exploit the final frontier.

Appendix A

Evolving Space Doctrine in the 90s

Space Superiority as an Air Force Core Competency

In 1994 the secretary of the Air Force set three goals for the Air Force in space. The first of these goals was to make space support to the war fighter routine. Air Force Space Command has made significant progress toward this goal and continues its intensive effort to provide timely, effective space support to war fighters commanding and executing conventional campaigns. As we rapidly move toward routine space operations for war–fighting support, the need to establish and maintain freedom of operations in space becomes increasingly critical. In a speech to the Air Force Historical Foundation in the fall of 1995, Secretary Sheila E. Widnall stated, “Space superiority has emerged as a critical element of today’s military operations. Support from space is becoming the quintessential force multiplier.”[1] Indeed space superiority is one of five core competencies illuminated in the secretary of the Air Force and AF chief of staff’s recent Air Force Executive Guidance (fig. A-1). Core competencies are fundamental contributions provided by the Air Force for national security.

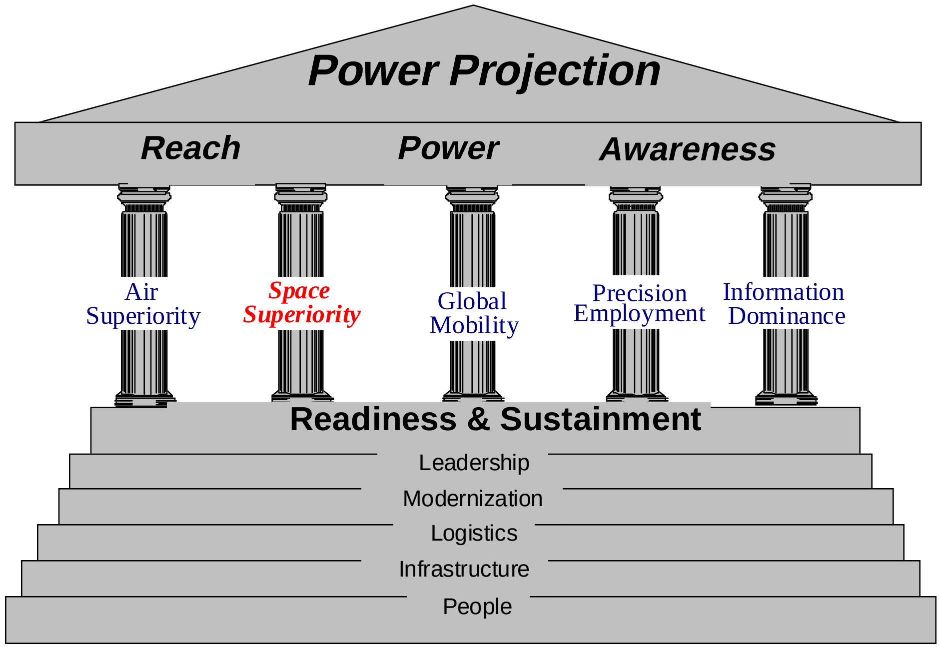

Figure A-1. Core Competencies.

These core competencies are founded on readiness and sustainment, and they support global reach, global power, and global awareness as air and space forces project power around the globe.[2] Space superiority as a core competency derives from deep historical roots dating to the 1950s in which the Air Force has led the way in space. Today, as the leaders in space, the USAF controls 80 percent of the Department of Defense (DOD) space budget and incorporates 90 percent of DOD's space personnel. The Air Force supports this core competency with an annual budget of $5 billion.[3] USAF space assets make a real and substantial contribution to US national security.

Space superiority involves a sufficient degree of control to ensure US and allied forces freedom of position, maneuver, employment, and engagement in space, and it involves the ability to deny this freedom to adversaries. To date the US has not had to fight to gain and maintain space superiority. This will change as the US becomes increasingly reliant on space forces to fight and win its wars, and as the use of space systems proliferates to more and more nations around the world. In recognition of this, the Air Force Executive

Guidance states the following assumption and guidance, "Air and Space superiority will continue to be an essential element of US war–fighting capability (as well as) fielding relevant, capable space forces is a modernization priority that spans the near-, mid-, and long-term."[4] In its discussion of Air Force core competencies, the draft Air Force Doctrine Document 1 (AFDD 1) equates space superiority to air superiority in terms of critical importance, and it recognizes that control of space may actually secure freedom of operations in all geographical environments.[5] Having explored space superiority as one of the five Air Force core competencies, it is now important to take a look at the evolving Air Force doctrine for this critical area.

Evolving Space Superiority Doctrine

Space superiority is achieved through counterspace operations. The current Air Force Manual 1-1 (Vol. II), *Air Force Basic Aerospace Doctrine*, March 1992, provides a limited treatment of counterspace under "Aerospace Control Missions." The document categorizes offensive counterspace operations as those conducted against an enemy's systems which operate in space, and defensive counterspace as missions to defend against attacks by systems operating in space. The key discriminator in differentiating between counterair missions and counterspace missions is the location of the target. If the target resides in space then the mission is counterspace regardless of the medium from which the force is applied. If the target resides in the atmosphere, then the mission is counterair.[6] New and evolving doctrine gives more thorough treatment to the space medium.

The new draft Air Force Doctrine Document 1, *Air Force Basic Doctrine*, lays out space superiority as one of the Air Force's five core competencies. This new document along with a new draft Air Force Doctrine Document 4, *Space Operations Doctrine,* provides a more extensive treatment of those aspects of space forces which support control of space. Space control assures a level of freedom of friendly use of space while denying this freedom to the enemy. Counterspace controls activities both in and through the space environment. An important aspect to understand is counterspace operations may be conducted by air, land, sea, special operations, as well as space forces. Like counterair it includes both offensive and defensive aspects.[7]

Offensive counterspace operations can be of a lethal or nonlethal nature as they disrupt, deny, degrade, or destroy the enemy's space systems or the information they provide. Disruption is considered to be the temporary impairment of the use of space systems and normally does not involve physical damage. Jamming is a good example of disruption. Denial refers to the temporary elimination of the use of space systems but still does not normally involve actual physical damage. An example of denial would be cutting off power to critical ground nodes. Degradation takes things a step further by permanent impairment of the use of space systems, normally through physical damage. Attacks against ground nodes would be an example of this. Finally, destruction is physical damage which permanently eliminates the utility of the space system. Use of airpower to bomb a space uplink or downlink facility falls into this category. Offensive counterspace actions are taken at a time and place of our choosing and can include attacks from space– or terrestrial-based forces on any or all segments of the enemy's space systems to include space vehicles, ground stations, and the signals emanating from both.[8]

Defensive counterspace preserves the ability to operate freely in and through space by reducing or precluding the effectiveness of the adversary's counterspace capabilities. There are two types of defensive counterspace operations, active and passive. These are defined below.

> The objective of active defense is to detect, track, identify, intercept, and destroy or neutralize enemy space and missile forces. Active defense operations include maneuvering the satellite, deploying mobile ground links and terrestrial elements, and deploying decoys.
>
> The objectives of passive defense are to reduce the vulnerabilities and to protect and increase the survivability of friendly space forces and the information they provide. Passive defense includes measures such as encryption, frequency hopping, and hardening.[9]

The new draft doctrine also identifies two important contributing capabilities to the counterspace mission: surveillance and reconnaissance of space and ballistic missile warning. Surveillance and reconnaissance of space provide the situational awareness and targeting which are essential to conducting effective counterspace operations. In addition, both space-based and ground-based systems perform detection, tracking, and reporting of ballistic missile events. These functions are critical to determining potential ballistic missile threats to the North American land mass, US operations worldwide, as well as space systems.[10]

The preceding discussion of current and evolving doctrine is intended to provide a departure point for discussing counterspace operations in 2025. To circumscribe the remaining discussion, we must look to

where the Air Force leadership wants us to go in the relative near–term as we then leap to 2025. The Air Force Executive Guidance document provides vectors across all areas of core competency including relevant assumptions and specific guidance statements. These assumptions and associated guidance are of such importance that they are quoted here from the Executive Guidance:

Offensive Counterspace

Assumptions:

1. US reliance on space-based capabilities will continue to increase.
2. The number of national and non-national entities utilizing space-based assets to gain advantage will increase.
3. Space situational awareness is critical to space control.

Guidance

1. The Air Force will continue to improve its ability to disrupt, deny, degrade, or destroy adversary space assets or capabilities.
2. The Air Force must survey space and protect its ability to use space while preventing adversaries from interfering with that use.

Defensive Counterspace

Assumptions:

1. Protection, denial, and negation capabilities are core and essential to space control.
2. The Air Force must expect and be prepared to defend against attacks (physical or electronic) on our space systems and facilities.
3. Protecting and assuring US access to space systems employment is essential to protecting US vital interests.
4. Protection of national security space systems capabilities using traditional measures such as deception, ground/space segment hardening, and secure C^4I techniques and non-traditional measures through integration of defensive Information Warfare measures are necessary to achieve adversary uncertainty about US intentions, plans, and operations.
5. Protecting the Earth and our space-based assets against damage from extraterrestrial objects deserves consideration.

Guidance:

1. The Air Force must continue to enhance its denial, protection and negation capabilities.[11]

Although fairly general in nature, the three guidance statements above give us a leaping off point to imagine the road down which the Air Force must travel to achieve a truly robust counterspace capability in

the year 2025. One last data point for framing the challenge of future counterspace operations is to understand what counterspace capabilities the Air Force employs today.

How the Air Force Does Counterspace Today

Today our counterspace capabilities are limited and primarily defensive and passive in nature. To the extent possible, US military satellite systems are hardened against electromagnetic pulse and radiation. Currently, secure command, control, and communications techniques (frequency hopping, low probability of intercept/low probability of detection, and signal encryption) are employed. Communications crosslinking provides added survivability against ground station attacks and robust system employment. Satellite subsystems are designed and built with double and triple redundancy. Large satellite constellations such as the global positioning system are dispersed to allow for graceful degradation should a small number of satellites be lost from the constellation. In addition, satellites carry fuel on board for station keeping operations which, given sufficient warning, could be used for maneuvering to attempt to avoid attack. Clearly these measures fall into the defensive counterspace realm whereby we are trying to reduce the vulnerabilities and increase the survivability of friendly space forces and the information they provide.

Perhaps the greatest amount of infrastructure and effort in defensive counterspace today lies in the extensive battle management and command, control, and communications (BM/C^3) capability of the Space Defense Operations Center (SPADOC) at Cheyenne Mountain Air Force Base, Colorado. The SPADOC is responsible for defense of US and allied space systems through monitoring and reporting on unusual space activity and planning possible defensive countermeasures. It assesses possible threat attack information and determines which friendly systems are vulnerable. The SPADOC is a data fusion center with wide connectivity to all space systems owners and operators through the Space Defense Command and Control System.[12] In a hostile space environment such as that expected in 2025, today's simple countermeasure will not be sufficient to protect US space systems and critical nodes such as SPADOC will be vulnerable.

NOTES

[1] The Honorable (Dr) Sheila E. Widnall, secretary of the Air Force, "Space: No Longer a Secret," address to the Air Force Historical Foundation, Washington, D.C., 21 September 1995.

[2] *Air Force Executive Guidance*, December 1996, 5–6.

[3] Widnall.

[4] *Air Force Executive Guidance*, 7-8.

[5] Air Force Doctrine Document 1, *Air Force Basic Doctrine* (First Draft*)*, 15 August 1995, 9.

[6] Air Force Manual 1-1, Vol. II, *Basic Aerospace Doctrine of the United States Air Force*, March 1992. 104-5.

[7] Air Force Doctrine Document 4, *Space Operations Doctrine (Proposed Final Draft)*, 8 November 1995, 4.

[8] Ibid, 4–5.

[9] Ibid, 5.

[10] Ibid.

[11] *Air Force Executive Guidance*, 9.

[12] AU-18. *Space Handbook*. Vol. 1, *A Warfighter's Guide to Space* (Maxwell AFB, Ala.: Air University Press, 1993), 103.

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